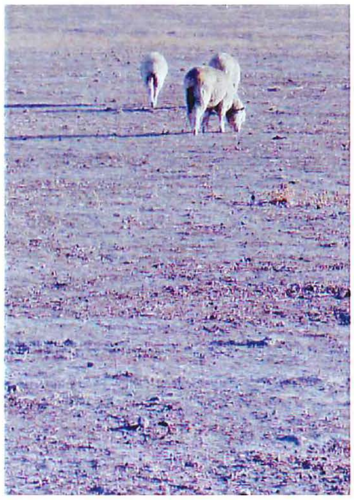
THE WATER RESOURCES OF THE WAIPARA CATCHMENT AND THEIR MANAGEMENT





A Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in Environmental Science in the University of Canterbury

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ABSTRACT

The Waipara catchment, North Canterbury, New Zealand is currently experiencing rapid intensification in land use from pastoral farming to viticultural, horticultural and lifestyle activities. This intensification has lead to escalating demand for water which has created challenges for the Waipara community and the water managers. Sustainable and effective management requires both a thorough understanding of the physical environment and consideration of the needs of society. This study has been undertaken to assist management by quantifying the water resources, determining current water use and identifying the key issues facing management.

Limited precipitation and high evapo-transpiration rates dominate the area's water resources resulting in very limited runoff and significant soil moisture deficits over the summer months. The surface water resources of the area are over allocated with potential abstraction rates far exceeding normal summer flows. The last five years has seen the rapid development of groundwater as landowners look for alternative irrigation supplies. The groundwater resources are very complicated and highly variable consisting of small discrete buried river channels. Recharge rates are very low which questions the long term sustainability of groundwater resource.

There is a need to move towards integrated catchment management where science and the community work together to create workable and appropriate solutions. The Waipara community are already highly active in water management. Similarly, recent science has improved understanding of the resources. Water managers need to cease the opportunity and begin the process of developing a holistic catchment management plan.

ACKNOWLEDGEMENTS

Firstly I would like to thank Environment Canterbury and particularly Michael Dicker of the Groundwater Section for the extensive logistical support which made this project possible. My supervisors Heidi Ellemor and Ian Owens thanks for your guidance, advice, continuing words of encouragement and for making sense of my seemingly endless drafts.

I would particularly like to thank the residents and landowners of the Waipara catchment, you all live in a very special part of the world. Your desire to fully understand and sensibly manage the water resources in the Waipara area was a continual inspiration especially during the many periods when I was struggling to understand the intricacies of the Waipara's water resources. For the many landowners that I met thanks for your time, providing access to you properties, sharing your theories and generally supporting this study. I hope this document is of use to you and that it assists in the management of Waipara's water resources.

Special thanks go to the staff of the groundwater section of Environment Canterbury for providing equipment, assisting with field work, answering my many queries, providing advice, putting up with my computer hopping and most importantly making the groundwater section a fun and enjoyable environment.

Thanks Mum and Dad for your ongoing support, for wading through my drafts and for helping to keep me sane.

Most importantly I would like to thank Denissa for living with this thesis, the many ups and downs over the last two years, and for being there for me throughout. Without your support this wee book would never have been finished. The many hours you spent proof reading and correcting my unintelligible initial drafts will not be forgotten.

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SECTION ONE

INTRODUCTION AND DESCRIPTION OF THE STUDY AREA

1 - INTRODUCTION

1.1 BACKGROUND

As demand for a resource increases, the fair and effective allocation of that resource becomes progressively more difficult. These challenges are faced no more so, than in regard to water resources in the Waipara catchment, North Canterbury, New Zealand (Figure 1-1). In Waipara, the combination of periodic drought, limited water resources, high demand for water use, and an incomplete understanding of the area's hydrology and hydrogeology, has created numerous challenges for Environment Canterbury and, to a lesser extent, the Hurunui District Council.

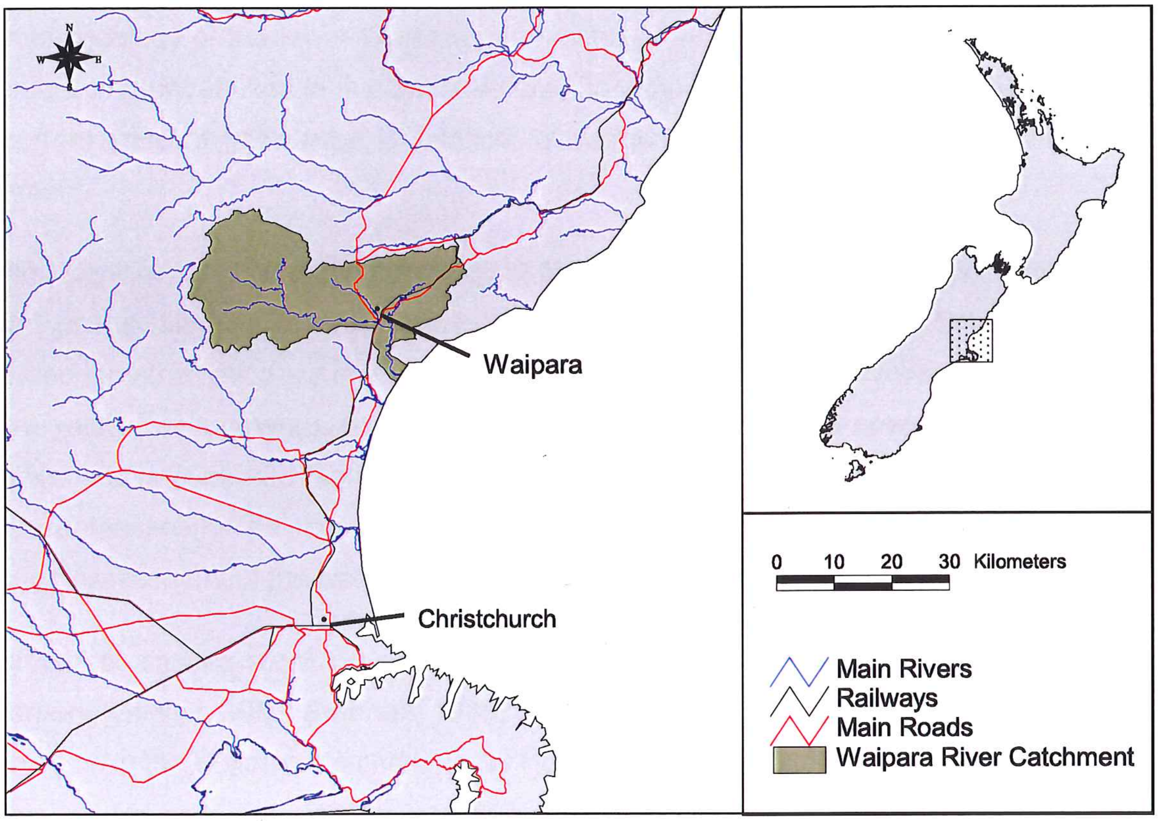


Figure 1-1 The Waipara Catchment, North Canterbury, New Zealand

Effective resource management stems from a thorough understanding of the resource. The water resources of the Waipara catchment have been the subject of numerous recent studies (Jowett, 1994; Pattle Delamore Partners and Canterbury Regional Council, 1996; Loris, 2000; Finnemore and Pettinga, in press; Larking, in press). These studies have vastly improved understanding; however they have tended to concentrate on individual aspects of the environment. Environment Canterbury plans to complete a holistic catchment management plan for the Waipara Catchment by 2005. As such there is a need to collate the existing information on the water resources of the Waipara catchment and to fill any knowledge gaps.

1.2 PREVIOUS WORK

1.2.1 THE WAIPARA CATCHMENT

Wilson (1963) provides the most comprehensive description of the geology of the Waipara area. More recent investigations (Harris, 1983; Nicol, 1991; Campbell and Nicol, 1992; Nicol et al., 1994; Nicol and Campbell, 2001) have explained how regional tectonic activity has influenced the geomorphology of the Waipara area and have provided some indication as to the timing of events. In June 2000 the Natural Hazards Research Centre of the University of Canterbury produced a revised geological map of the Waipara Area (Jongens, 2000) at a scale of 1:35,000 which represents all the geological mapping that has occurred over the last 15 years. Loris (2000) represents the most complete and up-to-date summary of the geology and hydrogeology of the lower Waipara catchment. Loris' work along with seismic surveys currently being undertaken in the Omihi Valley (Finnemore and Pettinga, in press), represent the current state of knowledge in relation to the geology and hydrogeology of the lower catchment.

The first significant study on the hydrology of the area was undertaken by Heiler et al. (1977) as part of the planning for and development of the Glenmark Irrigation Scheme. Heiler calibrated a mathematical runoff model to extend the flow record from Weka Creek. Over the last 10 years Environment Canterbury and its predecessors, have produced a number of published and unpublished reports on the water resources of Waipara, as well as maintaining various databases. The most significant of these was Horrell (1992), which provided a thorough assessment of the water resources of the whole catchment.

A number of studies have been undertaken on the general weather patterns of North Canterbury (Goulter, 1982; Sturman, 1986; Ryan, 1987). However, the only detailed study of precipitation in the Waipara Catchment was Horrell's (1992) work.

The soils of the area were initially mapped by the New Zealand Soil Bureau during the general mapping of the soils of the South Island. As part of this process a detailed report was produced for the soils of the Kowai County which covered the area south of the Waipara River (Fox et al., 1964). Griffiths (1980) undertook a detailed remapping of the soils of the Waikari District to the north of the catchment. As part of the development of the Glenmark Irrigation Scheme, the soils present in the catchments of Home Creek, Omihi Stream and Weka Creek were mapped and their runoff characteristics estimated (Heiler et al., 1977).

1.2.2 CATCHMENT STUDIES AND WATER RESOURCE MANAGEMENT

The value of holistic whole catchment studies to quantify the impacts of both natural and anthropogenic change on land and water resources is well recognised (Australian Representative Basins Program, 1982; Bowden, 1999; Thompson, 1999). The establishment of New Zealand's representative basins programme between 1964 and 1976 (Toebes and Palmer, 1969; Toebes and Morrissey, 1970; Rodda, 1976) was a direct result of the desire to collect hydrological information for use in planning, resource management and environmental monitoring.

Integrated (or total) catchment management is widely recognised as an appropriate means for achieving sustainable management of water resources (Mitchell, 1990; Bowden, 1999; Loucks et al., 1999; Brizga and Finlayson, 2000; Memon, 2000; New Zealand Ministry for the Environment, 2000). An integrated approach to environmental management has been formalised in New Zealand through the enactment of the Resource Management Act (RMA) in 1991, which brought the management of land and water resources under one over-arching piece of legislation. To date, the practical application of the RMA has not generated the expected level of integration (Frieder, 1997; Bowden, 1999). The development of Catchment Management Plans via participatory approaches is seen as a method for achieving this integration.

Environment Canterbury and its predecessors have produced catchment plans for the Waimakariri and Opihi Rivers (Canterbury Regional Council, 1995 & 1995a) and are currently developing a management plan for the Ashley River which is situated immediately south of the Waipara catchment (Mosley, 2001 & 2001a). Environment Canterbury are also currently reviewing their water allocation and management strategies. "Water Our Future" (Canterbury Regional Council, 1999) summarises the review process and outlines how Environment Canterbury plans to allocate and manage water resources throughout Canterbury. The only formal catchment planning that has been undertaken in the Waipara area was the publication of an issues and options document (Canterbury Regional Council, 1993) which provided a brief summary of the area's water resources and highlights some of the management issues.

1.3 THE ISSUES

Over the last 20 years the Waipara catchment has experienced a rapid transformation in land use from pastoral farming to increased afforestation in the upper catchment and increased viticultural, horticultural and lifestyle activities in the lower catchment. This has led to a significant increase in the use of water (particularly groundwater) within the catchment. Many of the area's boreholes have very low yields, experience significant drawdowns during pumping and a number of the area's shallow wells go dry during periods of drought. Information suggesting that the groundwater resource is of limited size with slow recharge rates has raised concerns over the sustainability of groundwater use. Likewise the catchment's surface water resources are already heavily allocated. Low flow requirements for ecological purposes result in uncertainty for surface water abstractors who are required to cease abstraction when river flows drop below set values. Uncertainty of water supply has a large economic impact on users especially where high value crops are concerned and results in significant financial risk. Demand for the Waipara's limited water resources is already very high and is projected to increase, due to on-going land development. There is strong public pressure and mounting scientific evidence to suggest that the Waipara's water resources need to be managed very carefully.

The Resource Management Act 1991 delegates overall responsibility for the management and allocation of Waipara's water resources to Environment Canterbury, with the Hurunui District Council responsible for domestic water supply and land usage within the catchment. The lack of a holistic integrated catchment management plan has resulted in Environment Canterbury managing the allocation of the area's water resources via resource consents issued under the RMA. The increasing demand for water is placing increasing strain on the resource consent process with the last major surface water abstraction consent going to a hearing of the Environment Court.

1.4 AIMS AND APPROACHES

This study is undertaken to assist in the development of an integrated management plan for the Waipara catchment by providing information on the extent of the catchment's water resources and the issues associated with their allocation and management. The four major aims of this study are:

1. To accurately describe the extent of the surface water and groundwater resources of the Waipara Catchment and to complete a water balance for the catchment;
2. To identify current water use within the catchment;
3. To outline the main issues facing water management in the catchment; and

4. To make management recommendations to ensure that the water resources of the Waipara catchment are managed in a sustainable and efficient manner.

Water quality is not considered in this study and throughout this document water management should be taken as referring to management of the quantity and allocation of water resources.

In describing the area's surface water resources, precipitation and evapo-transpiration records from the surrounding rainfall and climate stations are collected and analysed to produce both a precipitation map for the catchment and soils water balances for various sites. The flow characteristics of the Waipara River and its major tributaries are determined from flow measurements undertaken at various sites throughout the catchment.

Details from recently drilled boreholes are used to update knowledge of the groundwater resources of the catchment. Two regional potentiometric surveys are undertaken to assess the change in groundwater levels over the 2000-2001 summer irrigation period. Similarly, three continually monitored water level sites are established in boreholes on the Glasnevin Flats to assess short term fluctuations in groundwater water levels.

Current water use within the catchment is determined from a detailed review of Environment Canterbury's consent files, interviews undertaken with all the consent holders and interviews with local landowners. Water use within the catchment has increased significantly over recent years due predominantly to changes in land use. Land use maps for 1976 and 2001 are produced as a means of documenting the land use changes and a predicted 2025 land use scenario is developed to assess future water demand.

The issues associated with managing the water resources of the Waipara catchment are determined from analysis of existing water usage, the extent of the resources, and interviews held with staff of Environment Canterbury and the Hurunui District Council and representatives from key stakeholder groups. During this process the existing monitoring programmes established by Environment Canterbury are reviewed.

To facilitate future use of the information collected during this study wherever possible ArcView GIS (Geographical Information Systems) is used to store and present the data.

The study is being undertaken in association with Environment Canterbury and the Water for Waipara Group, and it is hoped it will directly feed into the knowledge base used for managing the water resources of the Waipara catchment.

1.5 THESIS STRUCTURE

This document is separated into four sections and eight chapters as outlined below.

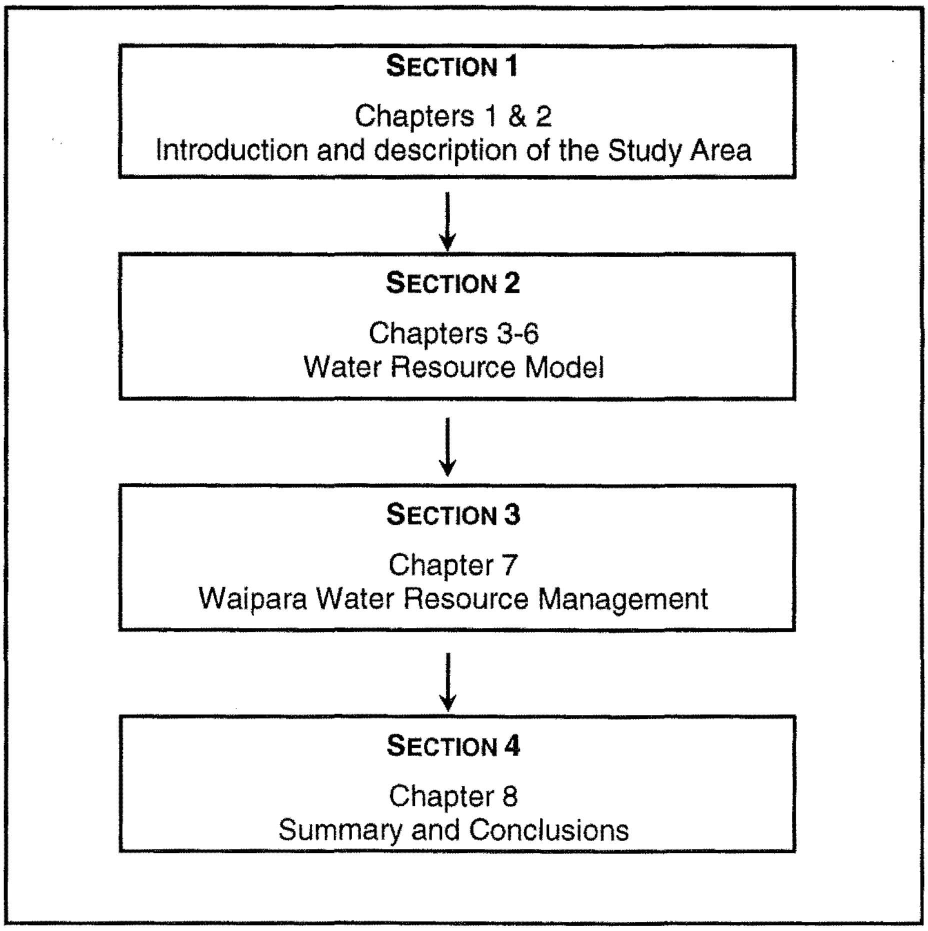


Figure 1-2 Thesis Structure

2 – THE STUDY AREA

2.1 OVERVIEW

The study area is the catchment of the Waipara River, on the northern fringe of the Canterbury Plains, South Island New Zealand (Figure 2-1). The catchment covers 740 km^2 and consists of foothills, an inland plain formed by the Waipara Alluvial Basin and a series of coastal hills. To allow the assessment of groundwater flow out of the catchment the study area is extended to cover the Glasnevin Flats which lie to the south of the Waipara catchment.

2.2 PHYSIOGRAPHY

The Waipara River is the main hydrological feature of the area. It flows approximately 70km from its source in the eastern foothills of the Southern Alps to its entrance into the Pacific Ocean at the northern end of Pegasus Bay. The catchment can be separated into two distinct parts; the steeper more rugged Upper Catchment and the Lower Catchment which covers the Waipara Alluvial Basin.

The Upper Catchment is bounded by the Cavandish Hills to the northwest (which include Mount Mason 853 m), the Okuku Ranges to the west (The Brothers 1092 m), and Mount Karetu (972 m) and Mount Grey (934 m) to the south. To the east, the Upper Catchment is separated from the Lower Catchment by the Doctors Hills (800 m), North Dean (573 m) and South Dean (571 m). The Upper Catchment is drained by four major tributaries: the North, South and Middle Branches of the Waipara River, and Tommys Stream. Between the Doctors Hills and the Okuku Range, the North Branch of the Waipara River flows south through the Upper Waipara River Valley. This valley extends to the north past the township of Masons Flat into the Amuri Plains (Figure 2-1).

The Lower Catchment is bounded by the Coastal Hills to the east (which include Mount Cass 525 m and Centre Hill 558 m), the North and South Dean to the west, and Mount MacDonald (491 m) and Moores Hill South (442 m) to the north. The area is dominated by the wide flat plains of the Waipara Alluvial Basin which extend to the south over the Glasnevin Flats. The Lower catchment is drained by two main tributaries Omihi Stream and Weka Creek (Figure 2-1).

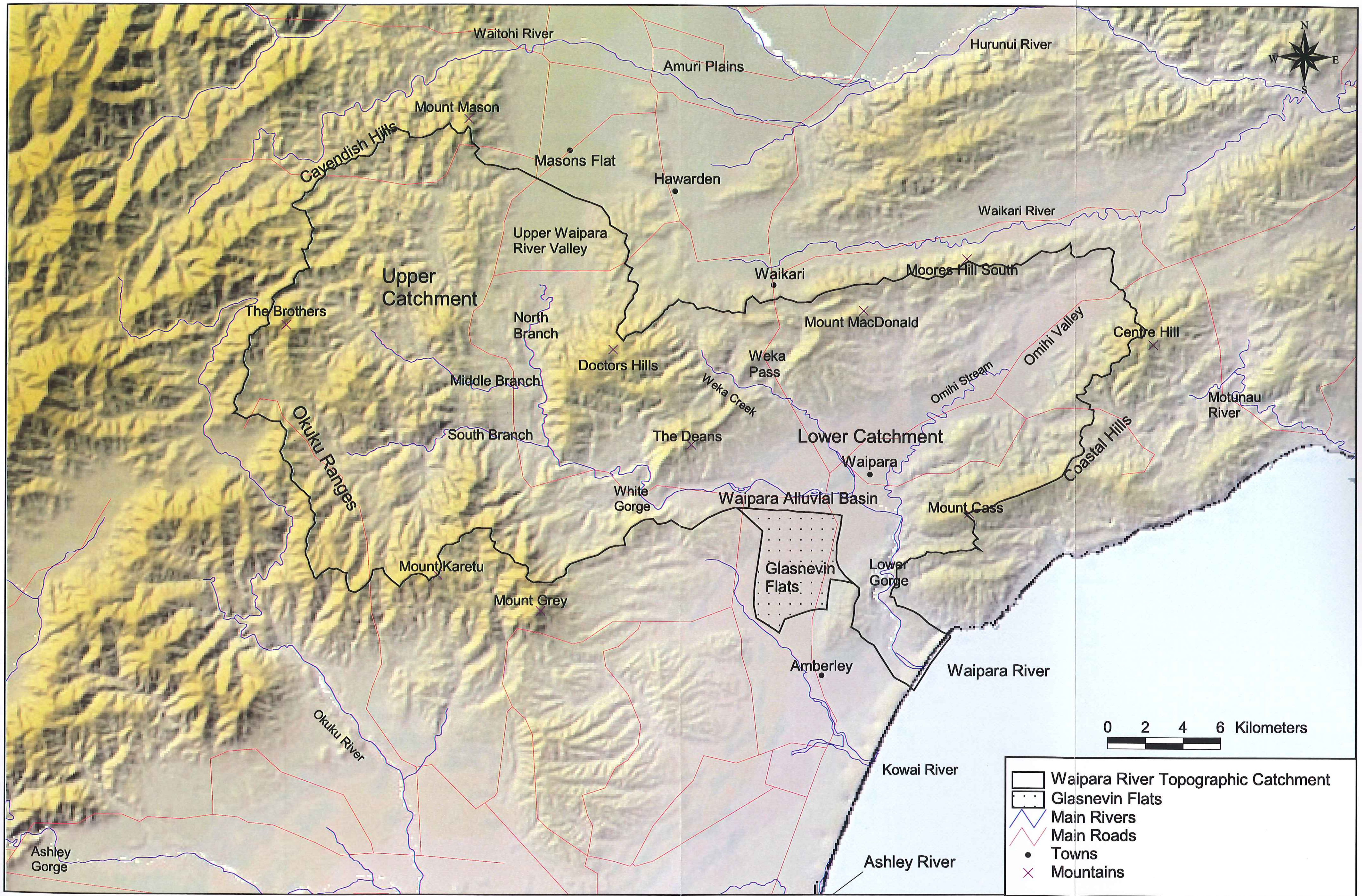


Figure 2-1 Waipara River Catchment, North Canterbury, New Zealand

2.3 GEOLOGY

The rocks of the Waipara Catchment were deposited during three distinct periods separated by major tectonic activity. The basement rocks consist of compacted sandstones and mudstones (greywacke and argillite) intermixed with sparse conglomerates and volcanics that were deposited during the Triassic and Jurassic. A period of metamorphism (Hokonui Orogeny) and several periods of erosion followed which are represented by a major unconformity in the rock record. The second period of deposition occurred from the mid Cretaceous to early Pleistocene when a marine transgression-regression sequence was deposited, which resulted in the Tertiary sandstone, mudstone and limestone rock units present within the catchment. A period of erosion followed which is highlighted by a second unconformity in the rock record. The onset of the Kaikoura Orogeny in the late Pleistocene resulted in rapid mountain uplift and extensive folding and faulting. Deposition of extensive fluvial and glacial gravels derived from erosion of the rapidly uplifting mountains, represents the final phase of rock deposition (Wilson, 1963; Gregg, 1964; Nicol, 1991). Ongoing local and regional deformation due to the Kaikoura Orogeny, results in the continued formation and growth of numerous folds (synclines and anticlines) and faults. A stratigraphic column for the area is presented in Figure 2-2.

The area is highly deformed with extensive folding and faulting associated with the nearby obliquely converging plate boundary between the Pacific and the Australian Plates. The main structural feature of the catchment is a series of northeast – southwest trending syncline and anticline pairs with associated fault traces formed by the compression and distortion of the pre-Cretaceous basement and Cretaceous-Tertiary sedimentary rocks. The anticlines have central ridges of basement greywacke and argillite and are flanked by the Cretaceous-Tertiary sedimentary cover (Wilson, 1963; Yousif, 1987; Nicol et al., 1994; Al-Daghastani and Campbell, 1995). The southwest plunging Waipara Syncline forms the large Waipara Alluvial Basin in the lower catchment, while the north to northeast plunging Macdonald syncline forms the upper Waipara river valley. Movement along various fault traces has resulted in displacement and distortion of the synclines although their general shape is easily recognised in the Geological Map for the area (Figure 2-3). Both synclines have been extensively infilled by fluvial and glacial gravels which forms the wide flats of the Omihi Valley, Glasnevin Flats and Masons Flat.

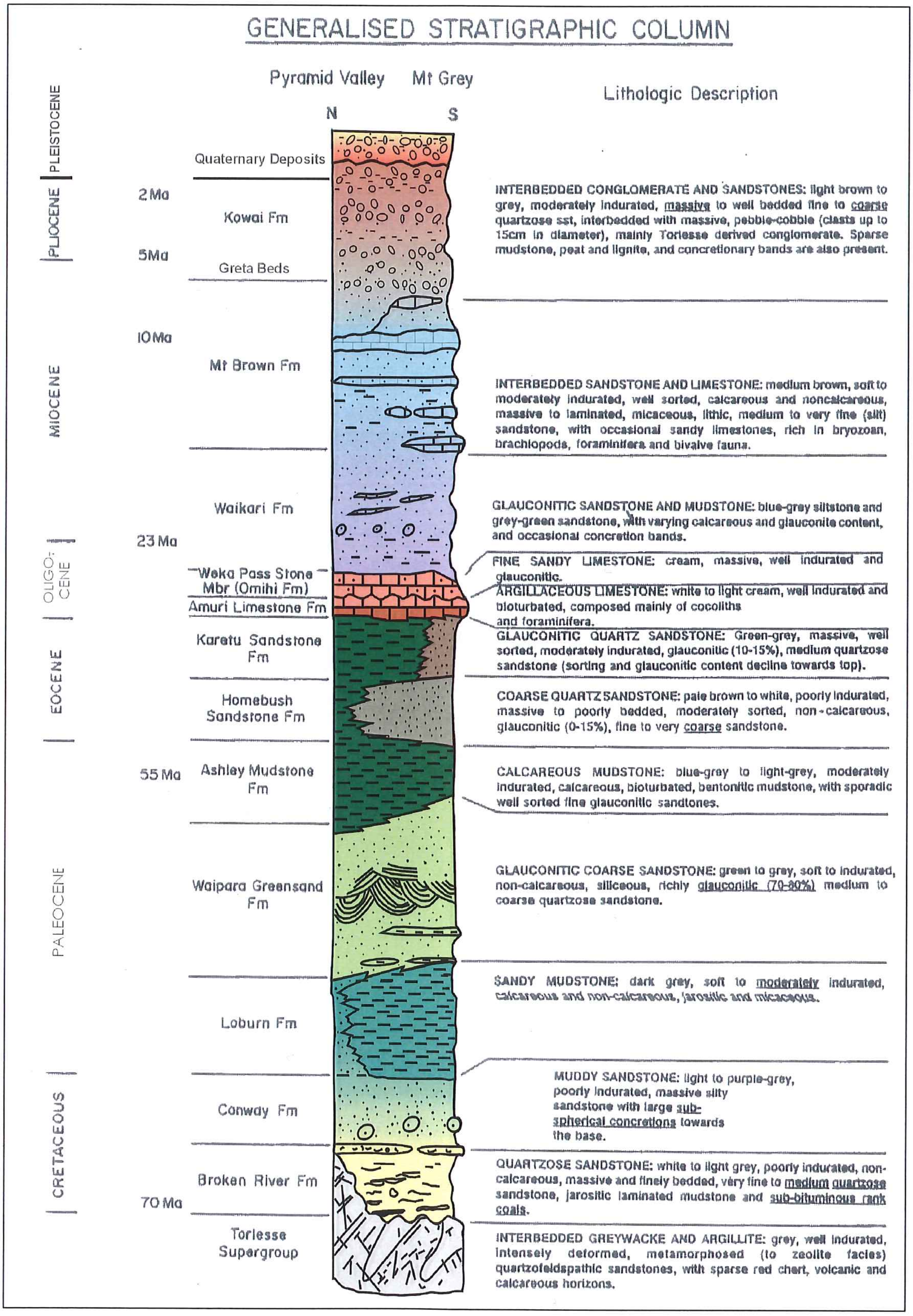


Figure 2-2 ***Stratigraphic Column for the Waipara Region*** *(Modified by Loris 2000, from Nicol 1991)*

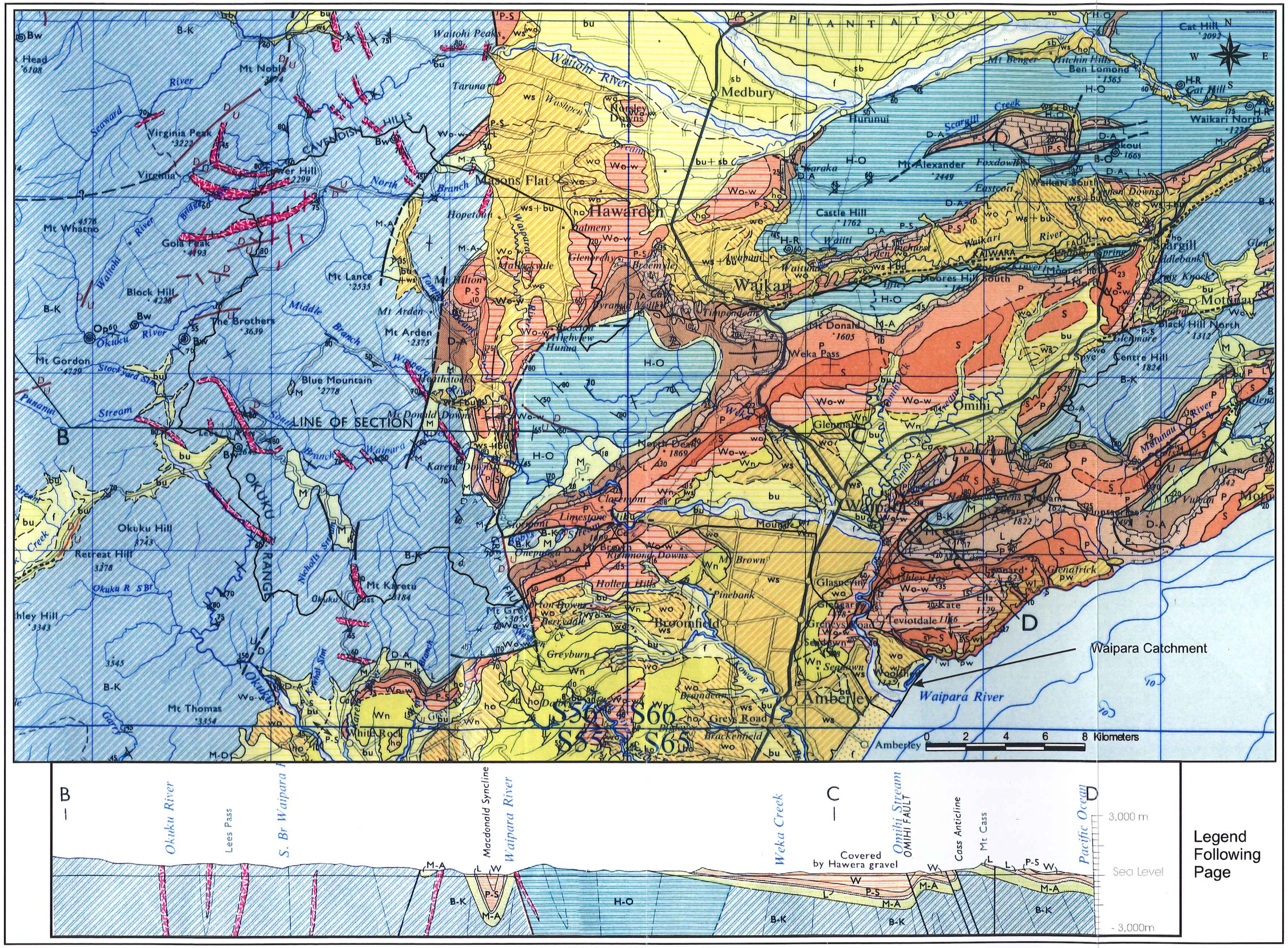
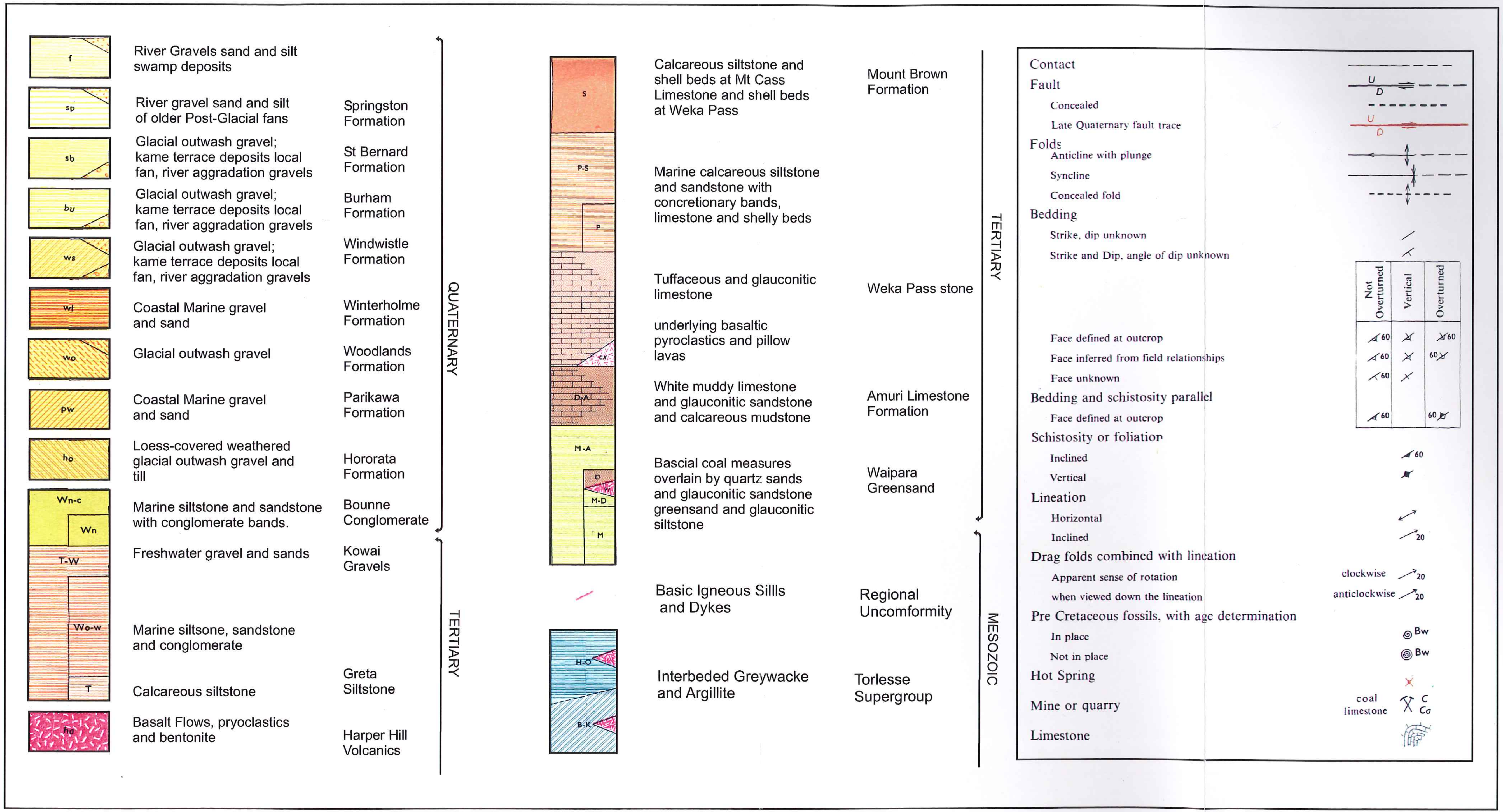


Figure 2-3: ***Geological Map of the Waipara Area, North Canterbury, New Zealand*** *(modified from Gregg 1964)*



Geological Legend (modified from Gregg 1964)

2.4 GEOMORPHOLOGY

The western portion of the upper Waipara Catchment is dominated by steep rugged terrain with slopes of 25-35° and incised mountain streams flowing down "v" shaped valleys. The area covers the eastern drainage faces of the Cavendish Hills, the Okuku Range, Mount Karetu and Mount Grey which rise to over 1000m above mean sea level. The valley floors are incised and represent streams downcutting through rapidly uplifting terrain.

The geomorphology of the mid and lower Waipara Catchment is dominated by the series of northeast-southwest trending syncline-anticline pairs. The synclines form the upper Waipara river valley and the Waipara Alluvial Basin, while the Doctors and Mount Cass anticlines form structural highs which flank the Waipara Alluvial Basin to the west and east respectively. Both anticlines are asymmetrical with steeper western limbs and more gently sloping eastern limbs as shown in the cross section in Figure 2-3.

Substantial infilling of the two main synclines by fluvial and glacial gravels resulted in the formation of large fan deposits and flat aggradational surfaces, the Mid Waipara Surface (Nicol and Campbell, 2001) and the Canterbury Surface (Wilson, 1963). Gravity (Loris, 2000) and seismic surveys (Finnemore and Pettinga, in press) suggest that gravels have infilled the Waipara Alluvial Basin to a depth of over 200m. Downcutting by the Waipara River and its tributaries resulted in various degradation surfaces (Wilson, 1963; Nicol and Campbell, 2001).

The Waipara River flows generally west to east crossing the syncline-anticline fold pairs. The river changes from a narrow deeply incised channel across the anticlines to a wide braided riverbed across the larger synclines (Nicol and Campbell, 2001). Downcutting by the river over the anticlines has formed three prominent gorges: Ohuriawa Gorge, White Gorge (Nicol, 1991; Nicol and Campbell, 2001) and the Lower Gorge (Al-Daghastani and Campbell, 1995). The presence of the gorges suggests that the Waipara River is an antecedent river and is geologically older than the uplifting which caused the formation of the Waipara Alluvial Basin.

2.5 SOILS

The varied geology and topography of the Waipara area causes a high degree of variability in the soil types present within the catchment (Figure 2-4). Soil type mirrors geology with shallow gravely silt loams derived from greywacke and argillite rocks covering the Okuku and Cavendish Ranges in the west of the Upper catchment as well as the central (higher) sections of the Doctors and Mount Cass anticlines. Moderately deep often calcareous sandy

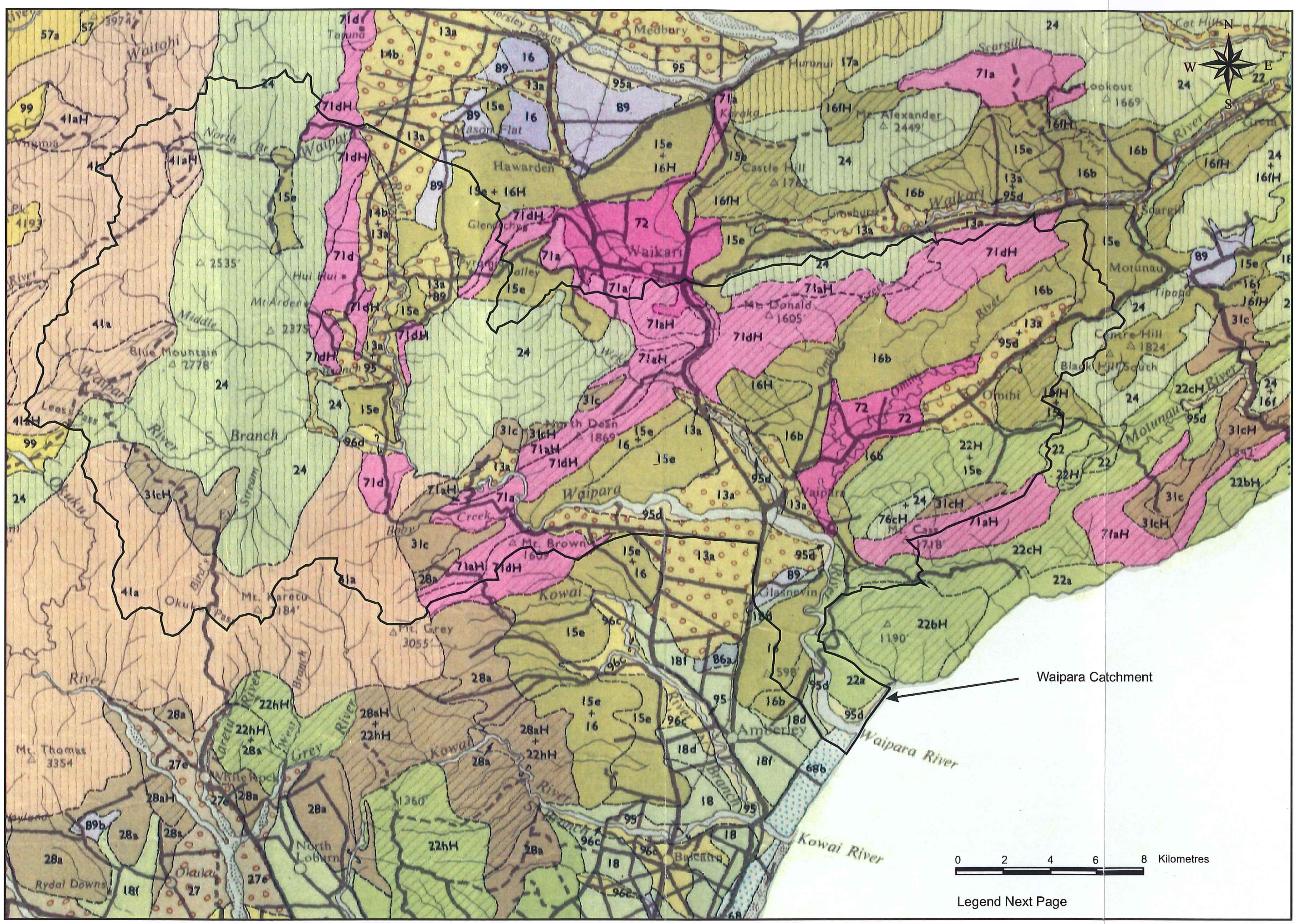


Figure 2-4 Soil Map of the Waipara Catchment *(Modified from NZMS Soils Map - Sheet 6, 1964)*

YELLOW-GREY EARTHS
(with related hill and steepland soils associated with yellow- brown soils)
Subhydrous
- on terrace lands and fans

Soil	Symbol	Hill symbol
Glasnevin	13a	
Culverden	14b	

- on rolling lands and hills

Soil	Symbol	Hill symbol
Waipara	15e	
Amberley	16	16H
Taiko		16aH
Glenmark	16b	
Tipapa	16f	16fH

Dry-hydrous
- on terrace lands and fans

Soil	Symbol	Hill symbol
Domett	18d	

- on rolling lands and hills

Soil	Symbol	Hill symbol
Cheviot	22	22H
Motunau	22a	
Stonyhurst		22bH
Glendhu		22cH
Leader		22gH
Makerikeri		22hH

- on steep lands and hills

Soil	Symbol	Hill symbol
Haldon	24	

YELLOW-GREY TO YELLOW-BROWN EARTHS INTERGRADE
(with related hill and steepland soils associated with yellow- brown soils)
Hydrous
- on rolling lands and hills

Soil	Symbol	Hill symbol
Okuku	28a	28aH
Onepunga	31c	31cH

LOWLAND YELLOW-BROWN EARTHS
(with related hill and steepland soils)
Hydrous
- on steep lands and hills

Soil	Symbol	Hill symbol
Hurunui	41a	41aH

RENDZINA AND RELATED SOILS
(with related hill and steepland soils)
Subhydrous to Hydrous
- on rolling lands and hills

Soil	Symbol	Hill symbol
Waikari	71a	71aH
Huihui	71d	71dH

Hydrous
- on terrace lands and fans

Soil	Symbol	Hill symbol
Omihi	72	

BROWN GRANULAR LOAMS AND CLAYS
(with related hill and steepland soils and associated soils)
Hydrous
- on rolling lands and hills

Soil	Symbol	Hill symbol
Cookson-Waikari		76cH

GREY SOILS

Soil	Symbol
Temuka	89

RECENT SOILS
(with intergrades to adjacent soils)
- on flood plains and young fans, from alluvium

Soil	Symbol
Waimakariri	95
Willowbridge	95d
Mayfield	96d

SOIL LEGEND

loam and clay loam soils derived from Tertiary sandstones, mudstones and limestones cover the rolling hills that flank the anticlines. The extensive fans that extend from the structurally high anticlines into the synclines are covered by shallow stony loam and sand soils at their crest and deep silty loam soils at their toe. The presence of buried soil layers within the fans indicate that fan building occurred over a number of phases. The older fans are generally derived from the erosion of loess and marls and contain finer material which produces silty soils. The middle age fans result from the erosion of sandstones and produce sandy loam soils whereas the youngest fans are the result of erosion of greywacke gravels and produce gravely sandy loams and sands. The valley floors are covered by intergrade soils consisting of various upslope soils mixed with recent soils. They are extremely variable and range from deep fertile clay loams in the mid reaches of the Omihi Valley to shallow stony silt loams adjacent to the Waipara River (Fox et al., 1964; New Zealand Soil Bureau, 1968; Griffiths, 1980).

A fragipan or compacted layer of subsoil has developed within many of the soils of the area that impedes drainage and root penetration. The fragipan varies in thickness but is usually approximately 25 cm thick and is situated at a depth of 40 to 60 cm below the ground surface (Griffiths, 1980). The pan hinders vegetation growth by trapping roots in the upper portion of the soil profile which rapidly dries out during the summer months. The presence of the pan has necessitated ripping during the development of most of the area's vineyards.

2.6 VEGETATION AND LAND USE

To document current vegetation and landuse in the Waipara catchment a 2001 landuse map age (Figure 2-5) was produced using Arcview. The vegetation layer of the digitised New Zealand Land Resource Inventory was used as a base which was refined using aerial photos held by Environment Canterbury (taken during 1995 at a scale of 1:27,000) and ground truthing.

The Waipara catchment is predominantly covered by high producing pasture and crop land (Table 2.1 and Figure 2-5). The steeper sections of the upper catchment and the tops of the Doctors Hills, the Deans, Mount Macdonald and the Coastal Hills are covered with short tussock vegetation, scrub (Manuka *Leptospermum scoparium*, Kanuka *Leptospermum ericoides* and Matagouri *Discaria toumatou*) and rough introduced grassland. Small remnants of the once widespread black beech forest with totora and hardwoods remain in isolated gullies.

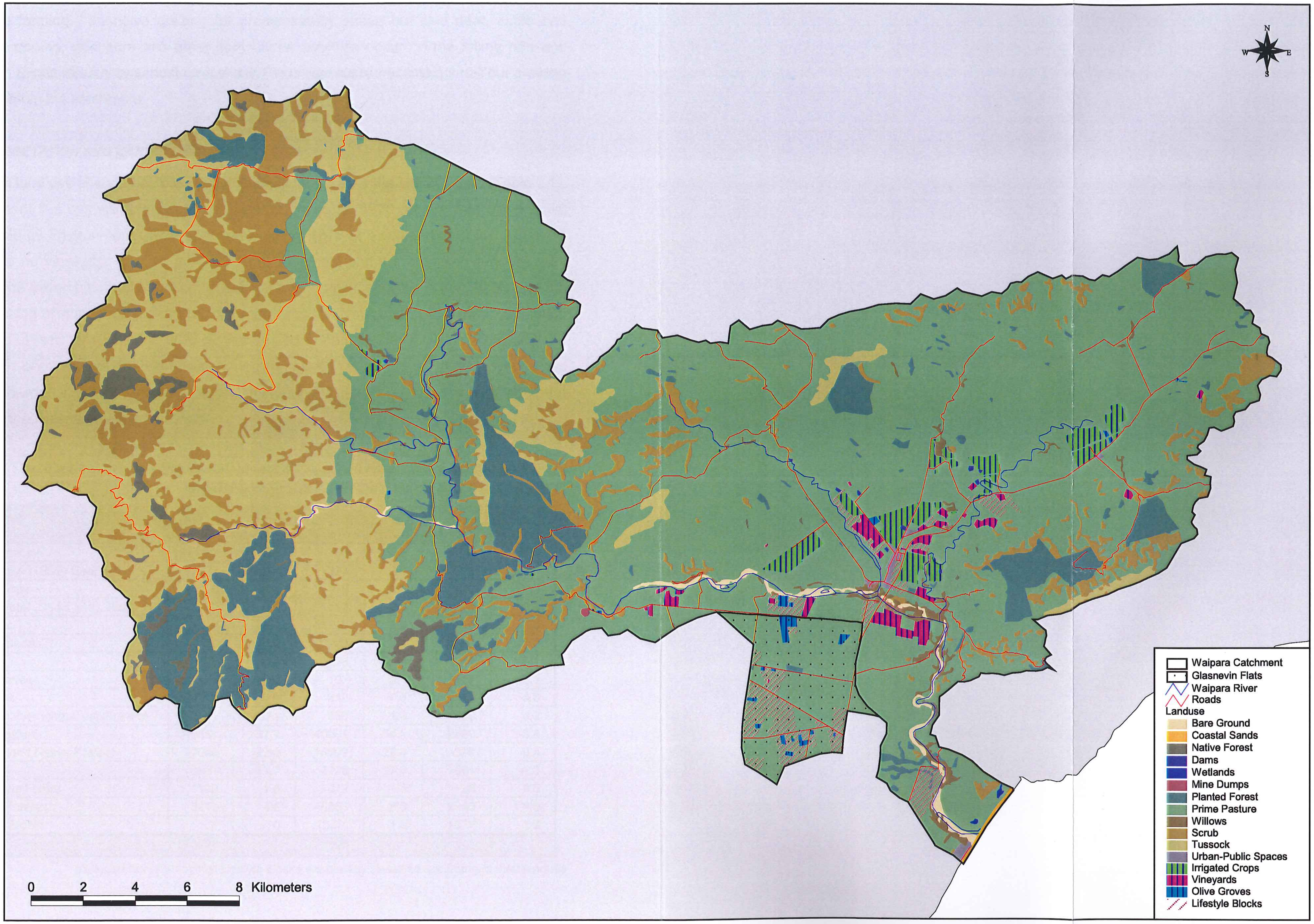


Figure 2-5 2001 Landuse Map for the Waipara Catchment

The steeper more rugged sections of the catchment are utilised for large run pastoral sheep and cattle farming. Intensive grazing (of predominantly sheep but also deer, cattle and ostrich), cropping, viticulture and other horticultural activities occur on the rolling hills and river flats. Exotic forestry of almost exclusively *Pinus Radiata* represents a small but growing land use within the catchment.

2.6.1 VEGETATION AND LANDUSE CHANGE

Significant land use change has occurred in the catchment over the last 25 years (Table 2.1). To document this change a landuse map was produced for 1976 (Figure 2-6) using aerial photos held by Environment Canterbury taken during 1976 at a scale of 1:10,000. In 1976 there were no vineyards or olive groves in the catchment and the area irrigated was very limited. The development of irrigation (the Glenmark irrigation scheme in the 1980's and the recent sinking of numerous boreholes) has lead to extensive areas of the lower catchment now being utilised for viticulture, olive groves and other horticultural activities. Similarly, the increase in popularity of lifestyle occupations has resulted in a number of larger properties being subdivided into lifestyle blocks particularly around Waipara Township and the southern portion of the Glasnevin Flats.

Table 2.1 Landuse within the Waipara Catchment & Glasnevin Flats 1976-2001 comparison

Areas determined from the landuse maps (Figure 2-5 and Figure 2-6)

Land Use	**1976**		**2001**		**Change**	
	ha	**%**	**ha**	**%**	**ha**	**%**
Urban Spaces	93	0.1	93	0.1	0	0.0
Bare Ground (River Bed)	327	0.4	327	0.4	0	0.0
Mine Dumps	9	0.0	9	0.0	0	0.0
Inland Water (Dams and Lakes)	2	0.0	19	0.0	17	0.0
Wetlands	10	0.0	10	0.0	0	0.0
Coastal Sands	29	0.0	29	0.0	0	0.0
Willows	597	0.8	556	0.8	-41	-0.1
Olive Groves	0	0.0	107	0.1	107	0.1
Vineyards	0	0.0	342	0.5	342	0.5
Irrigated other (crops, pasture etc)	41	0.1	739	1.0	698	0.9
Prime Pasture	42681	57.7	40001	54.1	-2680	-3.6
Tussock and Native Pasture	17008	23.0	16609	22.4	-399	-0.5
Scrub	8684	11.7	7723	10.4	-961	-1.3
Indigenous Forest	1102	1.5	1079	1.5	-23	0.0
Planted Forest	3413	4.6	6353	8.6	2940	4.0
Lifestyle Blocks	0*	0	1377*	1.9	1377	1.9
Total	**73996**		**73996**			

* excluded from the total as lifestyle blocks are already classified according to their landuse

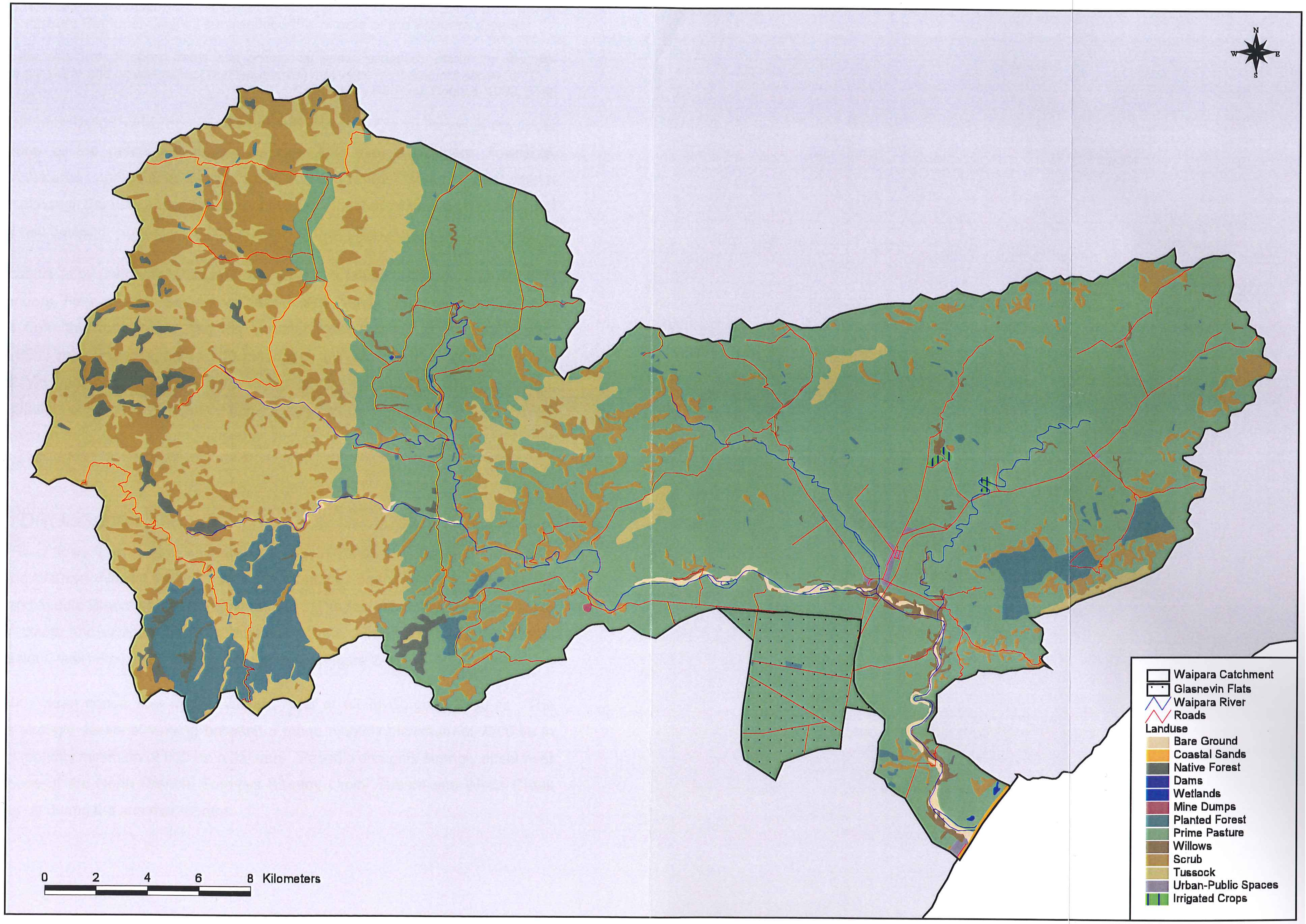


Figure 2-6 1976 Landuse Map for the Waipara catchment

2.7 CLIMATE

In 1993 the Canterbury Regional Council summarised the climate of the Waipara area as:

> *'Winters are cool with frequent frosts and occasional snow, especially about the foothills. Summers are warm and occasional hot north-westerlies may raise temperatures above 30 °C.'*
> (Canterbury Regional Council, 1993, p14).

Average annual precipitation varies from over 1100 mm along the Okuku Range in the upper western sections of the catchment to slightly over 600 mm at Waipara Township. Precipitation in the area is predominantly associated with airflow from the south-west, south-east and east, although the very upper sections of the catchment are situated on the edge of the north-west rain belt and experience minor amounts of precipitation from the north-west.

Precipitation occurs fairly uniformly throughout the year with March, July and August being wetter and January, February and September drier (NIWA, 1998). High temperatures and hot dry winds from the northwest during the summer months result in potential evapo-transpiration (PET) rates reaching up to 200 mm/month (NIWA, 1998). Records from the Waipara West Vineyard climate station in the lower catchment indicate that on average, monthly precipitation only exceeds monthly pan-evaporation during June and July (NIWA, 1998). Soil moisture deficits occur from November through to March which significantly limits vegetation growth.

2.8 HYDROLOGY

The Waipara River flows from west to east and drains both the eastern flanks of the Okuku Ranges and the Waipara Alluvial Basin. Four main tributaries drain the Okuku Ranges the North, South and Middle Branches and Tommys Stream. The four tributaries are fast flowing have steep gradients and exhibit a dendritic drainage pattern. Two main tributaries (Omihi Stream and Weka Creek) drain the Waipara Alluvial Basin (Figure 2-1).

The (1989-2000) mean annual flow in the Waipara River at White Gorge is 3148 l/s. The flow pattern is strongly seasonal varying between a mean monthly maximum of 7300 l/s in July to a mean monthly minimum of 500 l/s in January. Periodic droughts strongly affect river flow with sections of the North Branch, Tommys Stream, Omihi Stream and Weka Creek regularly drying up during the summer months.

2.9 WATER USAGE

Water use in the upper catchment is restricted to utilisation of surface water for stock and domestic use. There have been no resource consents issued to take either surface or ground water from the upper catchment. Presently there is very little stress on the upper catchment's water resources.

In contrast, usage of and demand for water is very high in the lower catchment. There are currently 29 resource consents that authorise the abstraction of surface water (including hydraulically connected groundwater) from within the lower catchment. The consents allow a maximum daily quantity of 124,588 m^3 to be abstracted at a maximum rate of 1,502 l/s (Environment Canterbury Consent Files 1 June 2001). A further 22 resource consents authorise the abstraction of up to 18,013 m^3 of groundwater per day at a maximum rate of 284 l/s. Significant volumes are abstracted from both surface and groundwater under Environment Canterbury's current bylaws that permit landowners to abstract small quantities of water for predominantly domestic and stock use.

Rural water supply schemes operated by the Hurunui District Council provide water for domestic and stock use throughout much of the catchment. The schemes bring 900 m^3 of water per day into the Waipara catchment from the Waitohi, Hurunui and Ashley rivers, as well as supplying Waipara Township with domestic water from nearby groundwater bores.

SECTION TWO

WATER RESOURCE MODEL

3 – CLIMATE

3.1 INTRODUCTION

The water resources of most catchments are strongly influenced by climatic conditions. It is therefore appropriate to commence this study with a description of the climate of the Waipara area. The aim of this chapter is to describe precipitation and evapo-transpiration and to briefly discuss how they influence both the extent of the Waipara's water resources and demand for their development and use. It is separated into two main sections covering precipitation and evapo-transpiration. Each section commences with a brief introduction and a discussion of previous work and then outlines the findings of this research. The main features of Waipara's climate are outlined in the conclusion of the chapter.

3.2 PRECIPITATION

3.2.1 INTRODUCTION AND PREVIOUS WORK

Despite there being a lot written about the general weather patterns of North Canterbury (Sturman, 1986; Goulter, 1982) the only detailed study of precipitation in the Waipara Catchment was undertaken by Horrell (1992). Horrell produced a 1961-1990 mean annual precipitation isohyetal map for the Waipara area based on precipitation records from 22 sites. He found that precipitation varied from about 1000 mm in the vicinity of Mount Grey and the Okuku Range to slightly less than 600 mm around the Waipara Township. Horrell found that precipitation in the area is associated with airflow from the south-west, south-east, east and north-east and is affected orographically by the Okuku Range and Mount Grey. This is consistent with Sturman (1986), who found that precipitation in North Canterbury is most strongly influenced by easterly airflow. This study builds on Horrell's earlier work by obtaining precipitation records from a further 13 sites and produces a detailed annual precipitation isohyetal map for the Waipara catchment.

3.2.2 PRECIPITATION RECORDS

Monthly precipitation records were obtained from 34 rain-gauge sites in and around the Waipara Catchment (Figure 3-1). The New Zealand Meteorological Service operates 19 of the sites and the records for these sites were obtained from the NIWA Climate Database. Environment Canterbury operates 6 of the sites as part of their North Canterbury rain-gauge network and the records were obtained from Environment Canterbury's hydrological database. The remaining 9 sites represent landowners' rain-gauges, the records for which were obtained from the individual landowners. The records are extensive, with 13 of the sites having in excess of 50 years of data and a further 9 having between 30 and 50 years. The rain-gauge sites are distributed throughout the Waipara area and vary in elevation from near sea level through to 817m. A description of each of the rain-gauges and a copy of the monthly precipitation records is given in Appendix 3.1.

3.2.3 NORMALISED PRECIPITATION

To allow comparison between sites, normalised precipitation over a standard period is required. To build on Horrell's earlier study and to take advantage of the additional records, a standard period of 50 years (1951-2000) was determined to be appropriate rather than the more standard 30 year period suggested by the World Meteorological Organisation (1962).

Data from the 35 sites was converted to 50 year (1951-2000) normals, using a combination of linear regression and direct correlation between sites (Appendix 3.2). The 1951-2000 Mean Annual Precipitation values obtained are summarised in Table 3-1. They indicate that annual precipitation varies from approximately 625 mm at Balmoral and the Waipara Township, to over 1400 mm along the Okuku Range in the west of the catchment. Comparison with Horrell's earlier work indicates that the 1951-2000 Mean Annual Precipitation values were approximately 3% higher than the 1961-1990 mean, suggesting that both the 1950s and the 1990s were wetter than average.

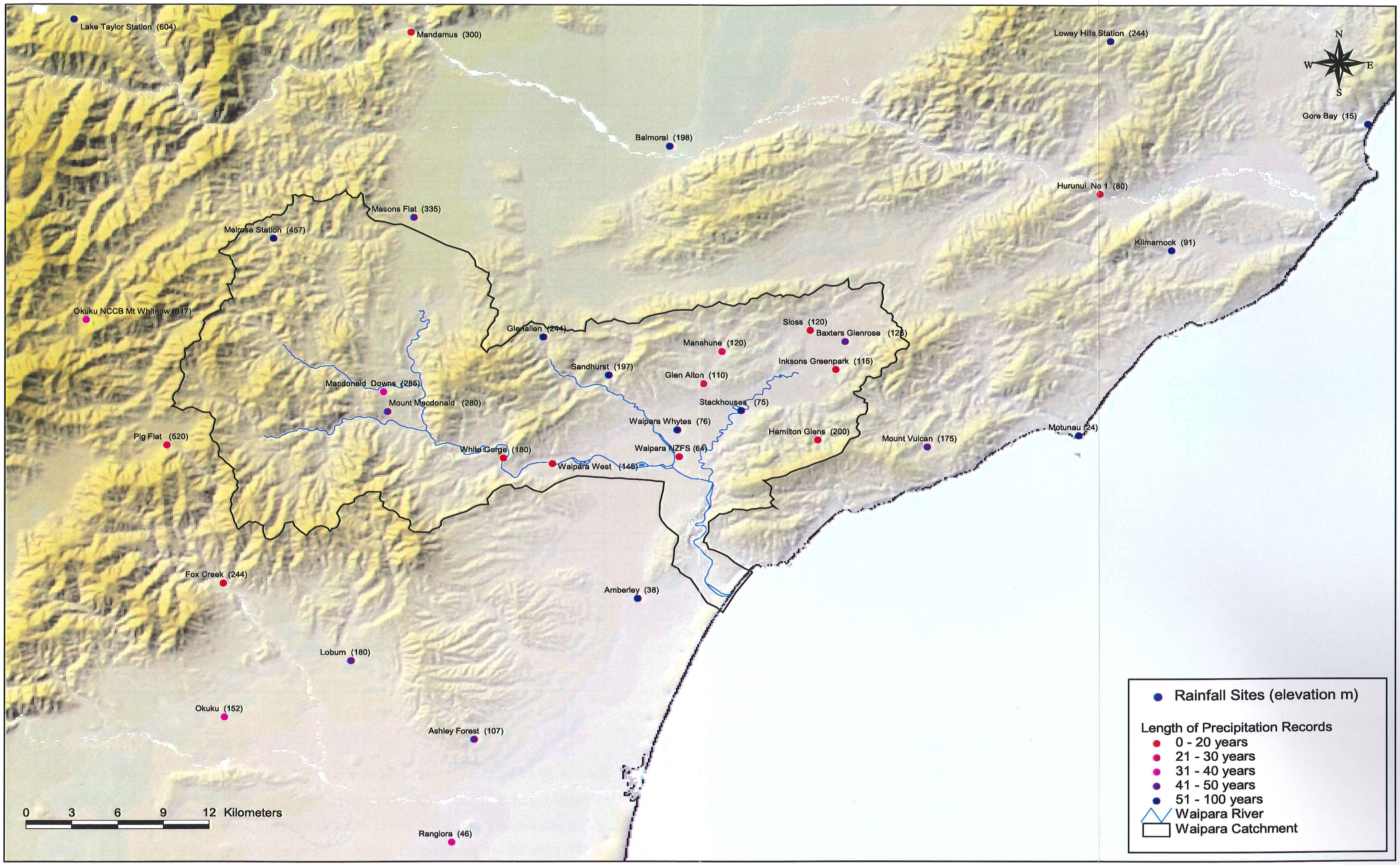


***Figure 3-1** Rain-gauge Sites in the Waipara Area showing the length of precipitation records and the elevation of the sites*

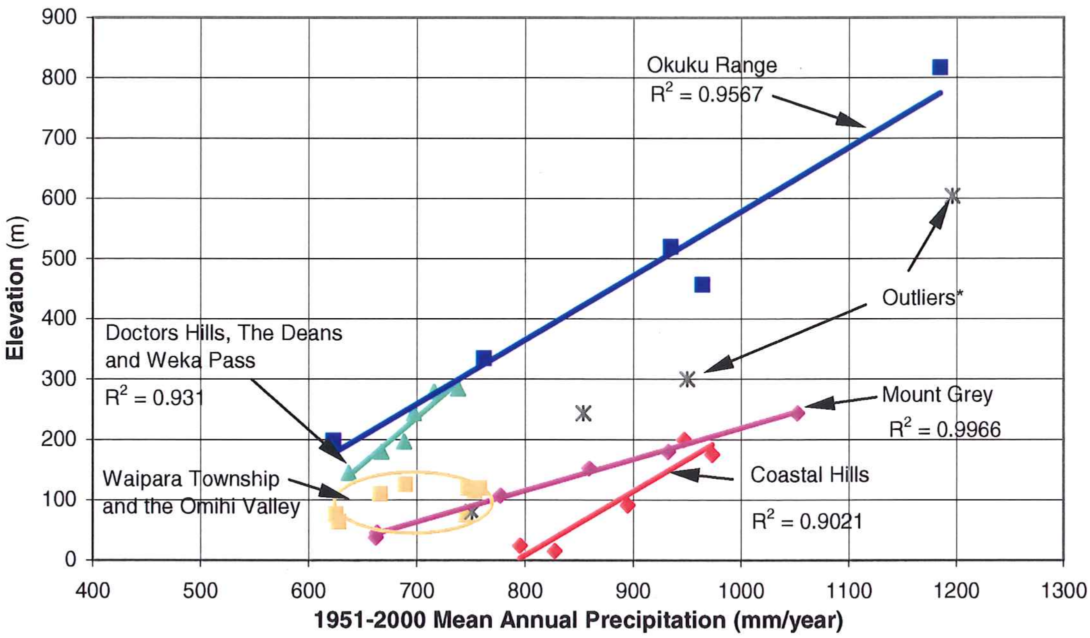
Table 3-1 1951-2000 Mean Annual Precipitation at various sites in the Waipara Region

Site Name	Site Number	Period of Records	Elevation m	1951-2000 Mean Annual Precipitation mm/year
Amberley Railway Terrace	H32171	1909-present	38	662
Ashley Forest	H32252	1941- 1990	107	777
Balmoral Forest	228710 [H22871]	1921-present	198	623
Baxter Glenrose	H4420	1954-present	125	689
Cheviot Area School	H23822	1982-1995	85	Used for regression only
Fox Creek	322410	1988-present	244	1052
Glen Alton	W02	1973-present	110	666
Glenallen	H22961	1905-present	244	697
Gore Bay	H23831	1915-present	15	827
Hamilton Glens	W09	1982-present	200	947
Hurunui No 1	239101	1992-present	80	751
Inksons Greenpark	W06	1986-present	115	753
Kilmarnock	H23911	1922-present	91	895
Lake Taylor Station	H22721	1947-present	604	1196
Loburn	H32242	1937-1984	180	932
Lowry Hills station	H23811	1947-present	244	854
MacDonald Downs	H32051	1939-1973	285	738
Manahune	W03	1974-present	120	758
Mandamus	282610	1988-present	300	950
Masons Flat	H22951	1960-1994	335	762
Melrose Station	H22941	1950-present	457	964
Motunau	H33003 [H33001]	1947-present	24	795
Mt MacDonald	W07	1956-present	280	716
Mt Vulcan	W08	1953-present	175	973
Okuku	H32232	1965-present	152	859
Okuku [NCCB]	H22921	1960-1978	817	1185
Pig Flat	321310	1976-present	520	935
Rangiora	H32325	1965-1999	46	663
Sandhurst Weka Pass	H32061 [H32071]	1920-present	197	688
Sloss	W05	1984-present	120	747
Stackhouse	W04	1950-present	75	745
Waipara NZ Forest Service	H32073	1973-1987	64	628
Waipara West	H32062	1990-present	145	637
Waipara Whytes	H32072	1923-present	76	625
White Gorge	321610	1988-present	180	667

3.2.4 *Precipitation Elevation Model*

The majority of rain-gauges (28 out of the 34) are manually read on a daily basis and are situated close to human activity at lower elevations and in valley floor positions (Appendix 3.1). The rain-gauge network tends to underestimate precipitation, as the records do not reflect hill top conditions. Precipitation was plotted against elevation for the 34 sites (Figure 3-2). If all the sites are considered precipitation is poorly correlated to elevation (R^2=0.49).

However, by grouping the sites according to similar position and topography, it was found that precipitation is strongly related to elevation. This indicates that localised weather patterns have a dominating influence on precipitation in the Waipara area.



* The four outliers (Hurunui No 1, Lake Taylor Station, Lowry Hills and Mandamus) are all situated to the north of the Waipara catchment and experience significant north-west rain.
Note the analysis was undertaken with precipitation as the dependent variable and then plotted as above to better reflect increasing precipitation with increasing elevation .

Figure 3-2 Plot of 1951-2000 Mean Annual Precipitation against Elevation

3.2.5 PRECIPITATION MAP

A Mean 1951-2000 Annual Precipitation map (Figure 3-3) was produced by the Golden Software Surfer 7.0 contouring program using kriging interpolation between the data points. Kriging interpolation was preferred over other contouring methods as it produces smooth contours that reflect natural events. Precipitation at all the major hilltops that surround the catchment was estimated using the precipitation elevation model described above (Section 3.2.4). To account for valleys, a number of intermediate sites were established by linearly interpolating between similar sites along the valley floor. To overcome edge distortion, sites were included well outside the catchment boundary and the resulting contours within the catchment are considered to be an accurate representation of actual precipitation patterns.

The varied nature of precipitation throughout the catchment highlights the influence of localised weather patterns. The Okuku Range to the west of the catchment receives the highest amounts of precipitation due predominantly to elevation, but also to its position on the edge of the north-west rain belt. Annual precipitation on the summit of the coastal hills exceeds 1200 mm, most of which is derived from southerly and south-easterly storms. The central part of the catchment including the Waipara Alluvial Basin, the Doctors Range and the upper Waipara River Valley, experience limited precipitation in the order of 700-800 mm a year. The limited precipitation over this area is primarily due to rain shadows created by Mount Grey and to a lesser extent the Coastal Hills. Storms from the south tend to be deflected by Mount Grey and either move inland along the Okuku Range or to the east along the Coastal Hills. The Coastal Hills produce a similar rain shadow effect to that of Banks Peninsula identified by Sturman (1986). Easterly storms tend to precipitate most of their moisture on the Coastal Hills with precipitation reducing inland.

Figure 3-3 closely resembles the 1961-1990 map produced by Horrell (1992). The only significant difference between the maps occurs along the Coastal Hills to the east of the catchment. Horrell's map indicates an annual precipitation of approximately 650 mm on the summit of Mount Cass and 700 mm on the summit of Centre Hill, compared with the 1200 mm and 1250 mm indicated by Figure 3-3. The difference is due to the inclusion of precipitation records from two sites within the coastal hills and Figure 3-3 is considered an improvement of Horrell's earlier work.

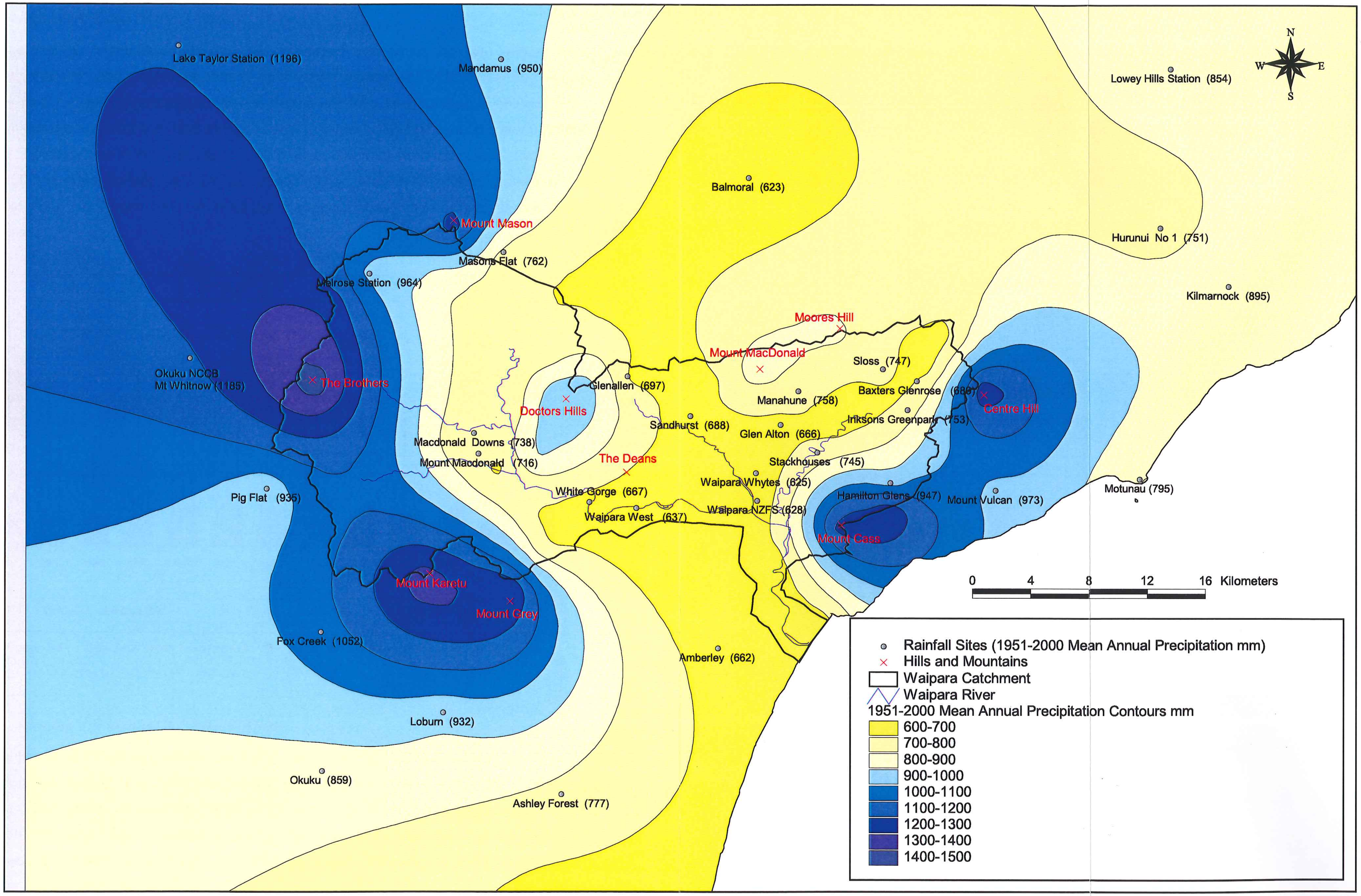


Figure 3-3 1951-2000 Mean Annual Precipitation Map of the Waipara Region

3.2.6 MONTHLY VARIATIONS IN PRECIPITATION

Average monthly precipitation remains fairly constant throughout the year (Figure 3-4). January, February and September tend to be the drier months with March, July and August slightly wetter. Monthly precipitation varies extensively from year to year as shown by the large maximum and minimum bars in Figure 3-4. This variability highlights the storm related nature of precipitation in the Waipara area, with large individual storms regularly causing well over 100 mm of precipitation in a 24 hour period. The variability of monthly precipitation is greatest along the Coastal Hills which experience regular coastal storms from the south and south-east.

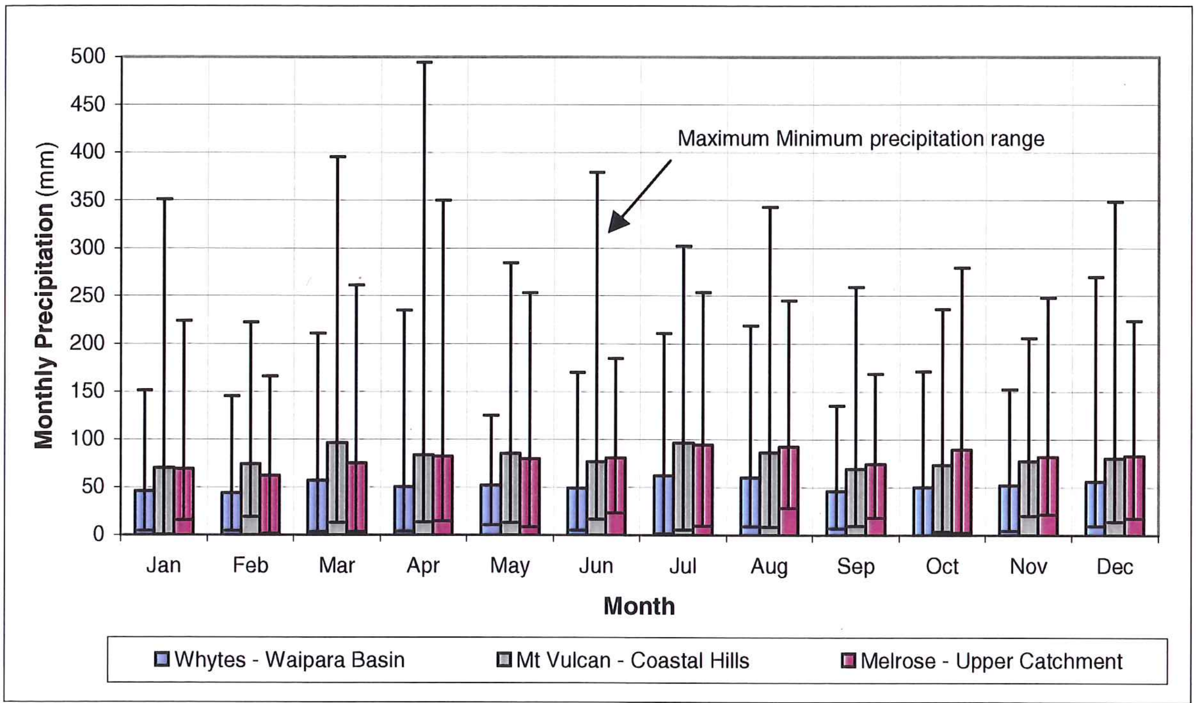


Figure 3-4 1951-2000 Mean Monthly Precipitation at various sites in the Waipara Catchment

3.2.7 ANNUAL VARIATIONS IN PRECIPITATION

Annual precipitation varied considerably during the period 1951-2000 (Figure 3-5). At Mount Vulcan in the coastal hills there was a 1125 mm variation between the driest (1964) and wettest (1978) years. At Melrose Station in the upper catchment the variation was 790 mm between 1969 and 1980. Similarly at the Whytes rain-gauge near the Waipara Township there was a 602 mm variation between 1969 and 1986. Variability in annual precipitation reduces inland with the coefficient of variability (standard deviation / mean) for annual precipitation reducing from 0.26 at Mount Vulcan, to 0.22 at Whytes, to 0.19 at Melrose.

The annual precipitation records from the Mount Vulcan, Whytes and Melrose Station rain-gauges indicate that all three follow a similar trend (Figure 3-5). This suggests that annual precipitation is controlled by regional weather patterns. High precipitation was recorded at all three rain gauges during the early 1950s, 1963, 1974-1980 and 1986. Low precipitation was recorded during 1964, 1969, 1988 and 1998.

The regional weather pattern is influenced by the El Niño / La Nina - Southern Oscillation phenomenon, with periods of El Niño often bringing stronger winds from the west during the summer which result in reduced rainfall and drought conditions along the east coast of New Zealand (NIWA, 1999). The effects of El Niño are shown in Figure 3-5 where low precipitation was recorded in 1958, 1969, 1972-73, 1982 and 1998, all of which were periods of strong El Niño conditions. Localised weather patterns can alter the effects of El Niño and it is noted that during the 1966, 1986-87 and 1990-94 periods of El Niño, precipitation in the Waipara area was average to above average and the severe drought of 1988-89 occurred during a non El Niño period.

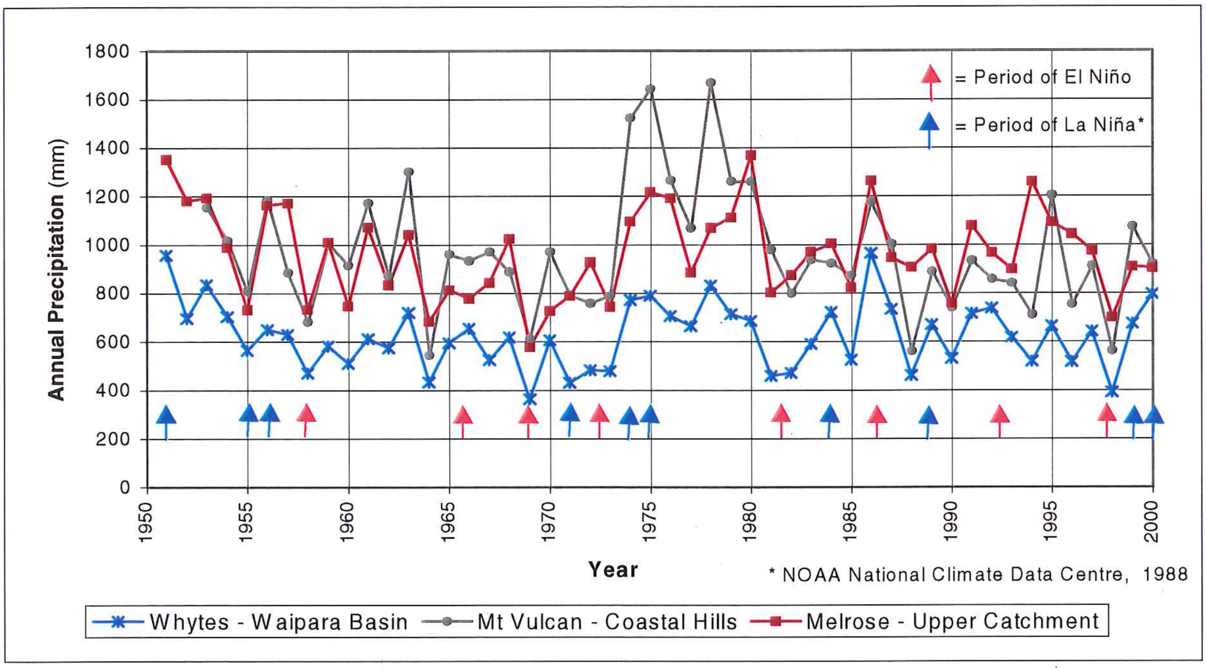


Figure 3-5 Annual Precipitation 1951-2000 at various sites in the Waipara Catchment

3.3 EVAPO-TRANSPIRATION

3.3.1 INTRODUCTION AND PREVIOUS WORK

In areas of limited precipitation such as Waipara, accurate assessment of evapo-transpiration is essential to effective water management. Where irrigation is undertaken, assessment of evapo-transpiration is required to determine irrigation scheduling and crop management. The scientific study of evaporation and transpiration processes is extensive and research can be traced back to Aristotle who concluded in the fourth century BC that *'wind is more influential in evaporation than sun'* (Rosenberg et al., 1968). The term evapo-transpiration is used to describe the total process of water transfer to the atmosphere from vegetative land surfaces and includes the combined effects of direct evaporation from water bodies and transpiration from vegetation.

Evaporation from water surfaces can be easily measured using evaporation pans, but the direct measurement of evapo-transpiration is difficult and requires the use of lysimeters. Numerous theoretical models have been developed which estimate evapo-transpiration based on pan evaporation measurements and various meteorological, climatic and biological properties. The theoretical term 'potential evapo-transpiration' (ET_p) was developed by Thornthwaite (1948) and Penman (1948), and relates to the evaporation from a standard reference crop which fully shades the ground, does not resist water flow and is always well supplied with water. Under the same weather conditions ET_p cannot exceed free water or pan evaporation. Actual evapo-transpiration (ET_A) is generally less than ET_p because actual water use depends on meteorological, plant and soil factors. Using ET_p in hydrological catchment studies is considered conservative as evapo-transpiration is overestimated. Thornthwaite (1955) developed a simple soil water balance for estimating ET_A from ET_p. The Thornthwaite soil water balance has been used successfully in a number of catchment studies including the development of the Glenmark Irrigation Scheme where a daily soil water balance was used to estimate flow in Weka Creek (Heiler et al., 1977).

No detailed studies of evapo-transpiration have been undertaken in the Waipara area. Recently a number of the Waipara vineyards have begun to use both neutron probes and pressure chambers to accurately measure soil moisture and vine stress (measurements of the effects of evapo-transpiration) as part of their irrigation scheduling. Open water evaporation losses from the Glenmark Irrigation Scheme storage dams were determined during the design of the scheme (Heiler et al., 1977).

This section analyses the potential evapo-transpiration data that is available for the Waipara area and uses a monthly Thornthwaite soil water balance to estimate actual evapo-transpiration from the catchment.

3.3.2 EVAPORATION RECORDS

Few evaporation or evapo-transpiration measurements have been made in North Canterbury (Table 3-2). The closest sites to Waipara with long term records are the Christchurch Airport and Hanmer Forest where records have been taken since 1953 and 1941 respectively.

Table 3-2 Evaporation and Evapo-transpiration data from the Waipara Area stored on the NIWA Climate Database as at 1 June 2001

Site Name and number	**Measurements undertaken**	**Length of Records**
Ashley Forest H32252	Penman	1980-1989
	Priestley Taylor	1968-1989
Cheviot H23822	Wet Pan Evaporation	1986-present
	Penman	1983-1995
	Priestley Taylor	1983-1995
Christchurch Airport H32451	Wet Pan Evaporation	1964-1994
	Penman	1953-present
	Priestley Taylor	1953-present
Culverden H22783	Penman	1983-1988
	Priestley Taylor	1983-1988, 1994-1997
Hanmer Forest G22581 and G22582	Penman	1941-1995, 1996-present
	Priestley Taylor	1941-1995, 1996-present
Rangiora H32364	Penman	1999-present
	Priestley Taylor	1999-present
Waipara West Vineyard H32062	Wet Pan Evaporation	1991-present

Wet Pan Evaporation measurements represent free water evaporation while both the Penman and the Priestley Taylor measurements are theoretical values of ET_p based on climate measurements. Both Penman and Priestley Taylor are combination methods that use climatological theories for both air temperature and solar radiation. The Penman method (initially developed over 50 years ago) still remains the most popular and widely used method for estimating ET_p (Burman and Pochop, 1994). Penman uses radiation theory to estimate evaporation from open water surfaces and then relates this to vegetated surfaces. In 1972 Priestley and Taylor found that in the absence of advection, ET_p is directly related to Equilibrium Evapo-transpiration (ET_{eq}). Equilibrium evapo-transpiration is the minimum possible evaporation rate from a moist surface and depends only on the temperature and available energy. The Priestley Taylor Method is semiempirical in nature and is considered a simplified form of the Penman Method (Rosenberg et al., 1983).

To account for transpiration effects and to utilise the longest period of data, the Priestley Taylor measurements were utilised for this study.

3.3.3 NORMALISED POTENTIAL EVAPO-TRANSPIRATION DATA

Hanmer Forest is situated 60 km north of Waipara Township while Christchurch Airport is 52 km to the south. The topography of Hanmer Forest (a flat inland basin surrounded by foothills) has a greater similarity to the topography of the Waipara catchment than the extensive flat plains that surround the Christchurch Airport. Due to the similar topography, potential evapo-transpiration rates at Waipara are expected to be similar to those at Hanmer Forest.

The Ashley Forest potential evapo-transpiration site (H32252) is situated on the lower flanks of Mount Grey approximately 15 km south of the Waipara catchment. The site receives moderate to high precipitation and is relatively sheltered from the hot dry north-west wind. Due to similar topography (steep and sheltered from the north-west), the potential evapo-transpiration rates measured at Ashley Forest are expected to be representative of the rates experienced along the Okuku Range and the steep western sections of the Waipara Catchment. The Cheviot site (H23822) is situated within the coastal hills some 32 km north-east of the Waipara Catchment. Potential evapo-transpiration rates measured at the site are expected to be representative of all the coastal hills including those within the Waipara catchment. Culverden (H22783) is situated within the flat dry Amuri Plains approximately 21 km north of the Waipara catchment. Potential evapo-transpiration rates measured at Culverden were taken to represent the central part of the Waipara catchment due to both areas being exposed to the hot dry north-west wind and receiving a similar level of precipitation.

A linear regression relationship model was established between Priestley Taylor records from Hanmer Forest and records from Ashley Forest, Cheviot and Culverden (Figure 3-6). Very good regression was achieved with the coefficient of determination (R^2) being greater than 98.0% for all the sites. This indicates that potential evapo-transpiration rates are controlled by regional weather patterns rather than localised ones. Using the regression relationships the 1951-2000 mean annual potential evapo-transpiration rates were calculated as 650, 678 and 682 mm for Ashley Forest, Cheviot and Culverden respectively. These rates are all slightly higher than the 614 mm measured at Hanmer Forest (G22581-82).

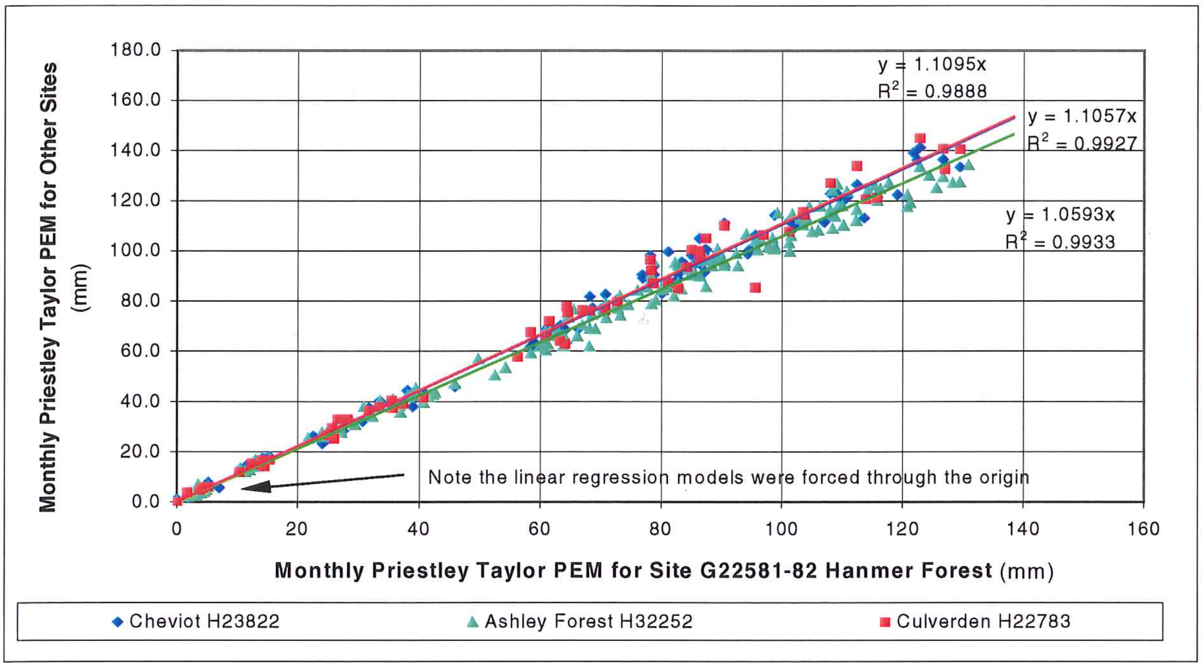


Figure 3-6 ***Linear Regression Plot of Monthly Priestley Taylor Potential Evapo-transpiration data from Hanmer Forest (site G22581-2) and various other sites around Waipara.***
(Data used for the Regression is contained in Appendix 3.3)

3.3.4 ACTUAL EVAPO-TRANSPIRATION

The Thornthwaite (1955) soil water balance is a book-keeping exercise where precipitation, potential evapo-transpiration rates and available water capacity for the soil are used to calculate plant available water (AW), actual evapo-transpiration (ET_A), soil water deficit (SWD) and runoff (RO). The water balance can be used on either a climatic basis (i.e. using average values) or on an actual yearly basis (i.e. using 'real-time' data for irrigation scheduling).

Thornthwaite (1955) defines two climatic conditions: climatic surplus and climatic deficit. A climatic surplus occurs when monthly precipitation exceeds potential evapo-transpiration allowing actual evapo-transpiration to occur at the maximum (potential) rate, i.e. $ET_A = ET_p$. During periods of climatic surplus, plant available water will increase and runoff will occur if the plant available water exceeds the available water capacity of the soil. A climatic deficit occurs when monthly precipitation is less than potential evapo-transpiration. Soil water is used to make up all or part of the climatic deficit. This results in the development of soil moisture deficits which restrict actual evapo-transpiration rates.

Thornthwaite soil water balances were undertaken at fourteen sites in the Waipara Area where monthly precipitation records were available for at least 12 years over the period 1951-2000. The normalised monthly ET_p records from Ashley Forest, Cheviot and Culverden were utilised to represent the Okuku Range, Coastal Hills and central portions of the catchment respectively. The site characteristics of each of the fourteen water balance sites are outlined in Table 3-3.

Table 3-3 Site Characteristics and Potential Evapo-transpiration records used for the soil water balances.

Site Name and Number	Area	Description and Local Climate	ET_p Record used
Amberley H32171	Lower catchment	Low elevation, flat plains, low rainfall, some coastal rain, exposed to dry north-west winds	Culverden
Baxters Glenrose H4420	Waipara Alluvial Basin	Low elevation, flat basin, low rainfall, dry, exposed to dry north-west winds	Culverden
Fox Creek 322410	Mt. Grey	High elevation, flanks of Mt Grey, high rainfall, some shelter from the north-west winds	Ashley Forest
Glenallen H22961	Doctors Hills	Mid elevation, hilly, low rainfall, within the rain shadow of Mt Grey, exposed to dry north-west winds	Culverden
Hamilton Glens W10	Coastal Hills	Mid elevation within the coastal hills, high rainfall derived from southerly and south-easterly coastal storms	Cheviot
MacDonald Downs H32051	Upper Waipara Valley	Mid elevation, valley floor position, medium rainfall within the rain shadow of Mt Grey, exposed to dry north-west winds	Culverden
Manahune W03	Weka Pass	Headwaters of Home Creek, mid elevation, within rain shaddow of Mount Grey	Culverden
Masons Flat H22951	Upper Waipara River Valley	Mid elevation, moderate rainfall, exposed to dry north-west winds	Culverden
Melrose Station H22941	Okuku Range	High elevation, mountainous, high rainfall situated on the edge of the north-west rain belt	Ashley Forest
Pig Flat 321310	Okuku Range	High elevation, mountainous, high rainfall situated on the edge of the north-west rain belt	Ashley Forest
Sandhurst H32061, H32071	Weka Pass	Mid elevation, hilly, low rainfall, within the rain shadow of Mt Grey, exposed to dry north-west winds	Culverden
Stackhouses W04	Waipara Alluvial Basin	Low elevation, flat basin, low rainfall, dry, exposed to dry north-west winds	Culverden
Waipara Whytes H32072	Waipara Alluvial Basin	Low elevation, flat basin, low rainfall, dry, exposed to dry north-west winds	Culverden
White Gorge 321610	Flanks of the Waipara Basin	Mid elevation, in gorge above the Waipara Alluvial Basin, within the rain shadow of Mt Grey, exposed to dry north-west winds	Culverden

Thiessens polygons were used to divide the catchment into 14 areas associated with the above sites. Soil data for each of the areas was obtained from the various New Zealand Soil Bureau maps which cover the Waipara area, Table 3-4. The available water holding capacity (AWC) for each of the soil units was determined by estimating the rooting depth and using the available water values outlined in New Zealand Standard NZS5103 (New Zealand Standard, 1973). The rooting depth was determined by assessing soil profiles for each of the units. Where barriers to root growth (namely pan layers) were present rooting depth was taken as the depth to the top of the pan layer, otherwise rooting depth was taken as the shallower of either the depth to the bottom of the B Horizon or 1200 mm.

Table 3-4 Soil types at various sites in the Waipara area

Site Name and Number	**Soils Present** obtained from the various soil maps for the area (Griffiths, 1980; New Zealand Soil Bureau., 1968; Fox et al., 1964)	**Available Water Capacity** (mm)
Amberley H32171	Amberley (16) + Glenmark (16b)	71
Baxters Glenrose H4420	Haldon (24), Waikari Hill Soil (71aH), Huihui Hill Soil (71dH), Glenmark (16b), Omihi (72), Tipapa Hill Soil (16fH) + Waipara (15e), Glasneven (13a) + Willowbridge (95d)	79
Fox Creek 322410	Hurunui (41a), Onepunga Hill Soils (31cH)	45
Glenallen H22961	Haldon (24), Waikari (71a), Waikari Hill Soil (71aH), Huihui Hill Soil (71dH), Onepunga (31c), Waipara (15e), Glasneven (13a) + Temuka (89), Amberley Hill Soil (16H)	56
Hamilton Glens W10	Waikari Hill Soil (71aH), Onepunga Hill Soils (31cH), Haldon (24) + Cookson-Waikari Hill Soils (76cH), Glendu Hill Soil (22cH), Cheviot (22H) + Waipara (15e), Tipapa Hill Soil (16fH) + Waipara (15e), Glasneven (13a) + Willowbridge (95d), Stonyhurst Hill Soil (22bH)	80
MacDonald Downs H32051	Hurunui (41a), Onepunga Hill Soils (31cH), Huihui (71d), Huihui Hill Soil (71dH), Mayfield (96d), Haldon (24), Onepunga (31c), Waipara (15e), Culverden (14b) + Glasneven (13a), Glasneven (13a) + Waimakariri (95), Glasneven (13a) + Temuka (89)	81
Manahune W03	Haldon (24), Waikari Hill Soil (71aH), Huihui Hill Soil (71d), Glenmark (16b), Omihi (72),	84
Masons Flat H22951	Haldon (24), Huihui Hill Soil (71dH), Huihui (71d), Temuka (89), Culverden (14b), Glasneven (13a), Waimakariri (95), Waipara (15e), Amberley (16H)	95
Melrose Station H22941	Hurunui (41a), Hurunui Hill Soils (41aH), Haldon (24), Waipara (15e)	65
Pig Flat 321310	Hurunui (41a), Onepunga Hill Soils (31cH), Haldon (24)	56
Sandhurst H32061, H32071	Haldon (24), Waikari (71a), Waikari Hill Soil (71aH), Huihui Hill Soil (71dH), Onepunga (31c), Waipara (15e), Amberley (16), Glasneven (13a), Omihi (72), Amberley Hill Soil (16H), Willowbridge (95d)	109
Stackhouses W04	Waikari Hill Soil (71aH), Haldon (24) + Cookson-Waikari Hill Soils (76cH), Glenmark (16b), Glendu Hill Soil (22cH), Cheviot (22H) + Waipara (15e), Stonyhurst Hill Soil (22bH), Omihi (72), Tipapa Hill Soil (16fH) + Waipara (15e), Glasneven (13a) + Willowbridge (95d)	101
Waipara Whytes H32072	Amberley (16) + Glenmark (16b), Domett (18d), Temuka (89), Glasneven (13a), Waikari Hill Soil (71aH), Glenmark (16b), Glendu Hill Soil (22cH), Cheviot (22H) + Waipara (15e), Amberley Hill Soil (16H), Willowbridge (95d), Motunau (22a), Stonyhurst Hill Soil (22bH), Omihi (72)	76
White Gorge 321610	Hurunui (41a), Glasneven (13a), Willowbridge (95d), Waipara (15e), Amberley (16), Waikari Hill Soil (71aH), Huihui Hill Soil (71dH), Onepunga (31c), Onepunga Hill Soil (31cH), Haldon (24)	87

To allow comparison with precipitation, the actual evapo-transpiration from the 14 sites was converted to 50 year (1951-2000) normals using direct correlation between sites (Appendix 3.2 method, Appendix 3.3 data). Thornthwaite soil water balances (Table 3-5) indicate that actual evapo-transpiration rates for the Waipara catchment are high with approximately 60% of the area's annual precipitation returning to the atmosphere via evapo-transpiration. Actual evapo-transpiration rates range from 429 mm per year in the Waipara Alluvial Basin to over 500 mm on the flanks of Mount Grey and along the Okuku Range and Coastal Hills.

Table 3-5 The Results of Thornthwaite Soil Water Balances for various sites in the Waipara Area

Site Name and Number	Period for Water Balance	Precipitation P	Potential Evapo-transpiration ET_P	Actual Evapo-transpiration ET_A	Soil Water Deficit*	Soil Water Surplus (runoff + infiltration)
		mm	mm	mm	mm	mm
Amberley H32171	1951-2000	662	682	437	245	225
Baxters Glenrose H4420	1951-2000	689	682	443	239	246
Fox Creek 322410	1988-2000	1052	650	514	140*	538
Glenallen H22961	1951-2000	697	682	459	223	238
Hamilton Glens W10	1982-2000	947	678	536	166*	411
MacDonald Downs H32051	1951-1973	738	682	451	230*	287
Manahune W03	1974-2000	758	682	495	192*	263
Masons Flat H22951	1960-1994	762	682	508	174*	254
Melrose Station H22941	1951-2000	964	650	521	129	443
Pig Flat 321310	1976-2000	935	650	495	146*	440
Sandhurst H32061, H32071	1951-2000	688	682	471	211	217
Stackhouses W04	1951-2000	745	682	483	199	262
Waipara Whytes H32072	1951-2000	625	682	429	253	197
White Gorge 321610	1988-2000	667	682	445	270*	222
Average		**781**	**675**	**478**	**201**	**303**

* for period of monthly records only

Calculations and Data in Appendix 3.4

The availability of water has a major influence over actual evapo-transpiration rates, with areas of high precipitation and/or soils with high available water capacity having the highest rates of actual evapo-transpiration. Annual soil water deficits of over 100 mm occur throughout the catchment. Large deficits of approximately 250 mm occur in the Waipara Alluvial Basin, Weka Pass and Doctors Hills areas and highlight the limited availability of water in these areas. Runoff from the same area is limited to less than 250 mm annually and runoff from the overall catchment is dominated by runoff from the high rainfall areas on the flanks of Mount Grey and along the Okuku Ranges and coastal hills.

The Thornthwaite soil water balances undertaken at Melrose Station, Whytes and Hamilton Glens highlight the strongly seasonal nature of actual evapo-transpiration, runoff and soil water deficit. At Melrose Station in the upper catchment, actual evapo-transpiration exceeds precipitation from November through to early February causing a significant soil moisture deficit to develop from December to March. Runoff from the catchment is very limited from November to March with the majority of the annual runoff occurring during the winter months of June to August (Figure 3-7). Similar trends are experienced at both the Whytes (Figure 3-8) and Mount Vulcan (Figure 3-9) sites. A soil moisture deficit occurs over a longer period (late October through to the end of March) at the Whytes site due to the reduced precipitation. Monthly soil water deficits of over 50 mm are experienced at Whytes from December to February which limit vegetation growth. The high soil water deficits result in demand for irrigation water and it is noted that much of the land surrounding the Whytes rain gauge is irrigated via either the Glenmark Irrigation Scheme or various other private schemes. Runoff at Whytes is essentially zero from October through to March, and significant volumes of runoff only occur in July and August.

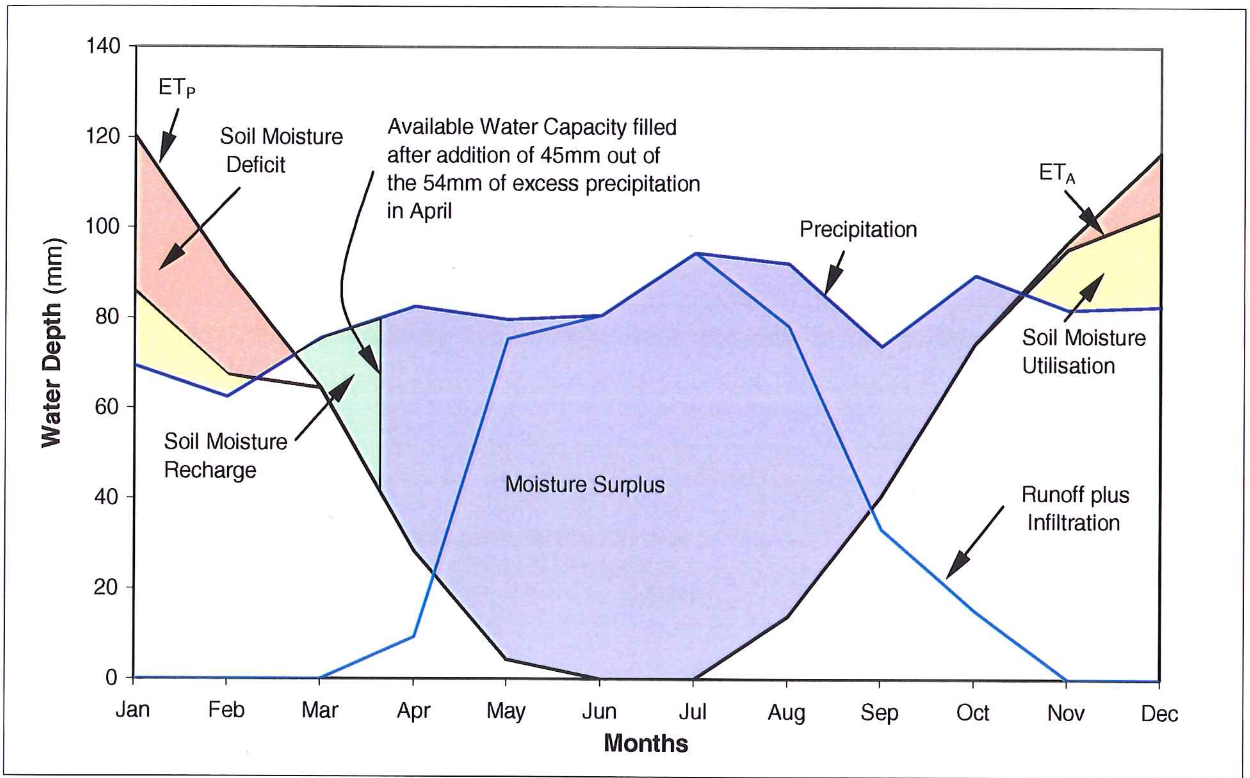


Figure 3-7 ***1951-2000 Mean Monthly Thornthwaite Soil Water Balance for the Melrose Station site in the Upper catchment***

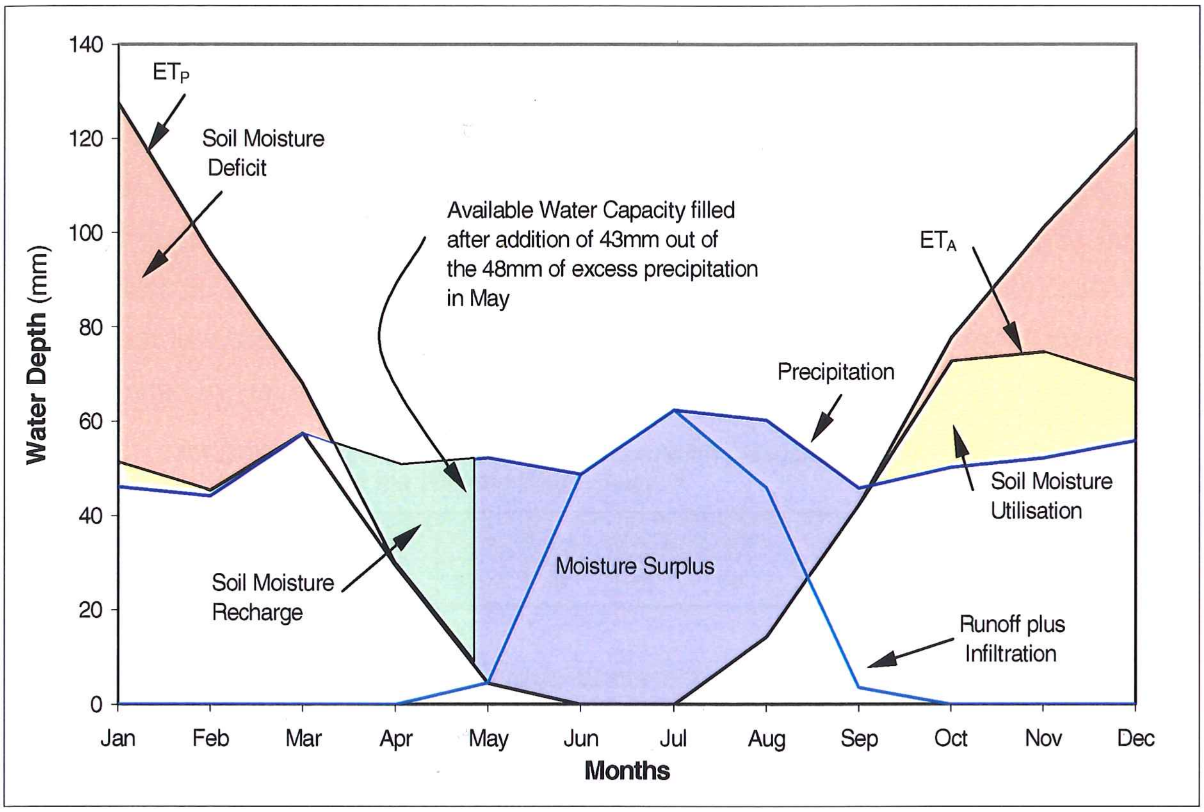


Figure 3-8 ***1951-2000 Mean Monthly Thornthwaite Soil Water Balance for the Whytes site near Waipara Township***

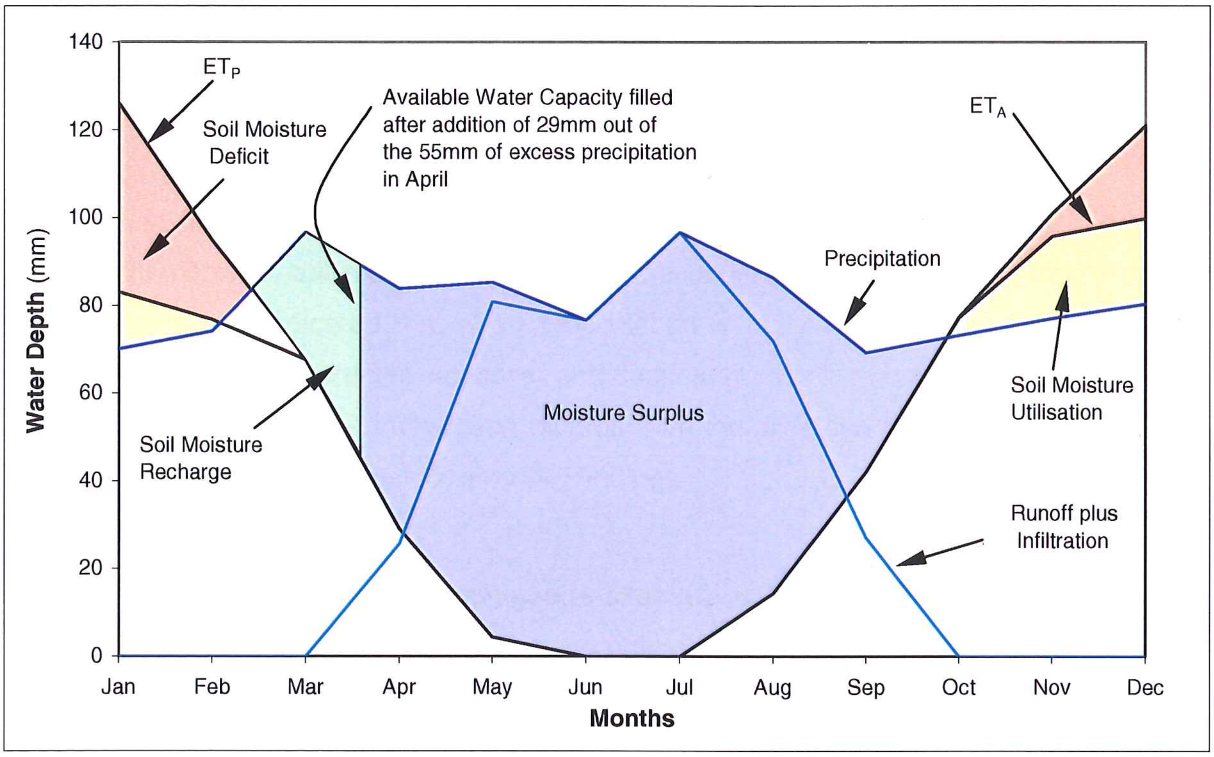


Figure 3-9 ***1951-2000 Mean Monthly Thornthwaite Soil Water Balance for the Mount Vulcan site in the Coastal Hills***

3.3.5 EVAPORATION FROM LAKES AND STORAGE DAMS

In the design of the Glenmark Irrigation Scheme, annual evaporation losses from the storage dams was calculated at 214 100 m^3 (Heiler et al., 1977). The calculation was based on an estimated annual evaporation loss of 600 mm determined from pan evaporation measurements from Lincoln. Wet pan evaporation measurements (Table 3-6) from the climate station at Waipara West Vineyard from 1991-2000 suggest that open water evaporation in Waipara is close to 1400 mm/year which is significantly higher than the 600 mm estimated by Heiler.

Table 3-6 ***1991-2000 Average monthly Wet Pan Evaporation measurements from Climate Station H32062 situated at the Waipara West Vineyard***

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
196	158	146	88	71	47	48	65	97	139	146	191	1392

The surface area of the 15 water storage dams and the two natural lakes in the Waipara Catchment is estimated at 44 ha from aerial photos of the area. Consequently the annual evaporation from lakes and storage dams in the catchment is estimated at approximately 600,000 m^3. This value does not account for the fact that in many of the storage dams, depletion by use is substantially complete by December and the dams are essentially dry over the period of highest evaporation. Evaporation from the streams, rivers, small stock dams and wetlands in the Waipara area is not considered to be significant and is not included in the above estimate.

3.4 SUMMARY

Precipitation and Evaporation data from the Waipara area coupled with information on the area's soils allowed soil moisture balances to be undertaken at fourteen sites. The soil moisture balances indicated that while precipitation is fairly constant throughout the year evapo-transpiration is extremely seasonal and dominates over the summer months. Analysis of precipitation and evapo-transpiration records from the area and the completion of the soil water balances resulted in the following key findings:

<u>Precipitation</u>

- Precipitation records from 34 rain-gauge sites are available in the Waipara area. The records are extensive with 22 sites having greater than 30 years worth of data.
- Five precipitation zones were identified.
  1. <u>The Coastal Hills</u> which receive high levels of annual precipitation (>800mm) due to coastal storms from the south, south-east and east.
  2. <u>The flanks of Mount Grey</u> which receive moderate to high levels of annual precipitation (650-1050 mm) which is strongly related to elevation.

3. The Okuku Range which lies on the edge of the north-west rain belt and receives the highest levels of annual precipitation (>900 mm).
4. The Doctors Hills, the Deans and Weka Pass area which is situated in a rain shadow created by Mt. Grey and receives limited annual precipitation (650-750 mm).
5. The Waipara Township and Omihi Valley which are situated in a rain shadow created by Mt. Grey and the Coastal Hills and receive very limited annual precipitation (600-700 mm).

- Within the first four precipitation zones, precipitation mirrors topography. In the fifth zone which covers the Waipara Alluvial Basin precipitation is fairly constant and does not vary significantly with elevation.
- Mean 1951-2001 annual precipitation varies from only 625 mm at Balmoral and the Waipara Township to over 1400 mm on the tops of the Okuku Range.
- Average monthly precipitation is fairly constant throughout the year, although localised high intensity storms result in significant variability in monthly precipitation from year to year. Variability in monthly precipitation decreases inland from the coast.
- Annual precipitation is highly variable and controlled by regional weather patterns.

Evapo-transpiration

- High potential evapo-transpiration rates of over 650 mm per year are experienced throughout the catchment and are controlled by regional weather patterns. Potential evapo-transpiration rates are highly seasonal peaking at over 120 mm per month in January and falling away to zero in June and July.
- Actual evapo-transpiration rates range from slightly over 400 mm to approximately 550 mm per year throughout the catchment. Actual evapo-transpiration is limited by the availability of water particularly during the summer months and is strongly influenced by the variability of soils throughout the catchment.
- Potential evapo-transpiration exceed precipitation over the summer months resulting in significant soil moisture deficits, which limit vegetation growth and create a large demand for summer irrigation water particularly in the Waipara Alluvial Basin.
- Annual pan evaporation rates of close to 1400 mm are recorded in Waipara resulting in an estimated 600 000 m^3 of water evaporating from the area's lakes and storage ponds annually.

Due to the dominant effect of evapo-transpiration over the summer significant runoff and infiltration to groundwater is only expected to occur over the winter months. This issue is further investigated in the following two chapters which look at the surface water and groundwater resources of the catchment.

4 SURFACE WATER RESOURCES AND USE

4.1 INTRODUCTION

The aim of this chapter is to describe the surface water resources of the Waipara catchment and their existing use so that management options can be discussed in later chapters. The chapter is separated into four sections covering river flows, development of a flow model, springs and finally a discussion of surface water storage in the catchment. Each section commences with a brief discussion of previous work undertaken and then describes the findings of this research. The existing use of the area's surface water resources is included within the chapter, as it is necessary to consider both the extent of the resource and existing usage when developing future management options. The main features of the surface water resources of the Waipara Catchment are outlined in a brief summary at the end of the chapter.

4.2 RIVER FLOWS

4.2.1 INTRODUCTION AND PREVIOUS WORK

The first investigations of the hydrology of the Waipara Catchment were undertaken in 1977 as part of development of the Glenmark Irrigation Scheme (Heiler et al., 1977). Heiler installed a weir on Weka Creek and used 3 ½ years of flow data to correlate a mathematical runoff model. The runoff model was then used to provide a flow record for Weka Creek from 1931-1975. Heiler also compared the flow characteristics of Weka Creek with both Home Creek and Omihi Stream and concluded that the runoff response of Home Creek and Omihi Stream was similar to that of the Weka Creek.

More recent work undertaken by Environment Canterbury and its predecessors included the establishment of a flow recorder at White Gorge in 1988 and subsequent audits of the recorder data (Lockington, 1992). A general description of the hydrology of the catchment was developed by Horrell (1992) as part of an issues and options paper for the management of the water resources of the Waipara region (Canterbury Regional Council, 1993).

The main hydrological features of the catchment are shown in Figure 4-1 including the main tributaries, the two recorder sites and the various flow gauging sites.

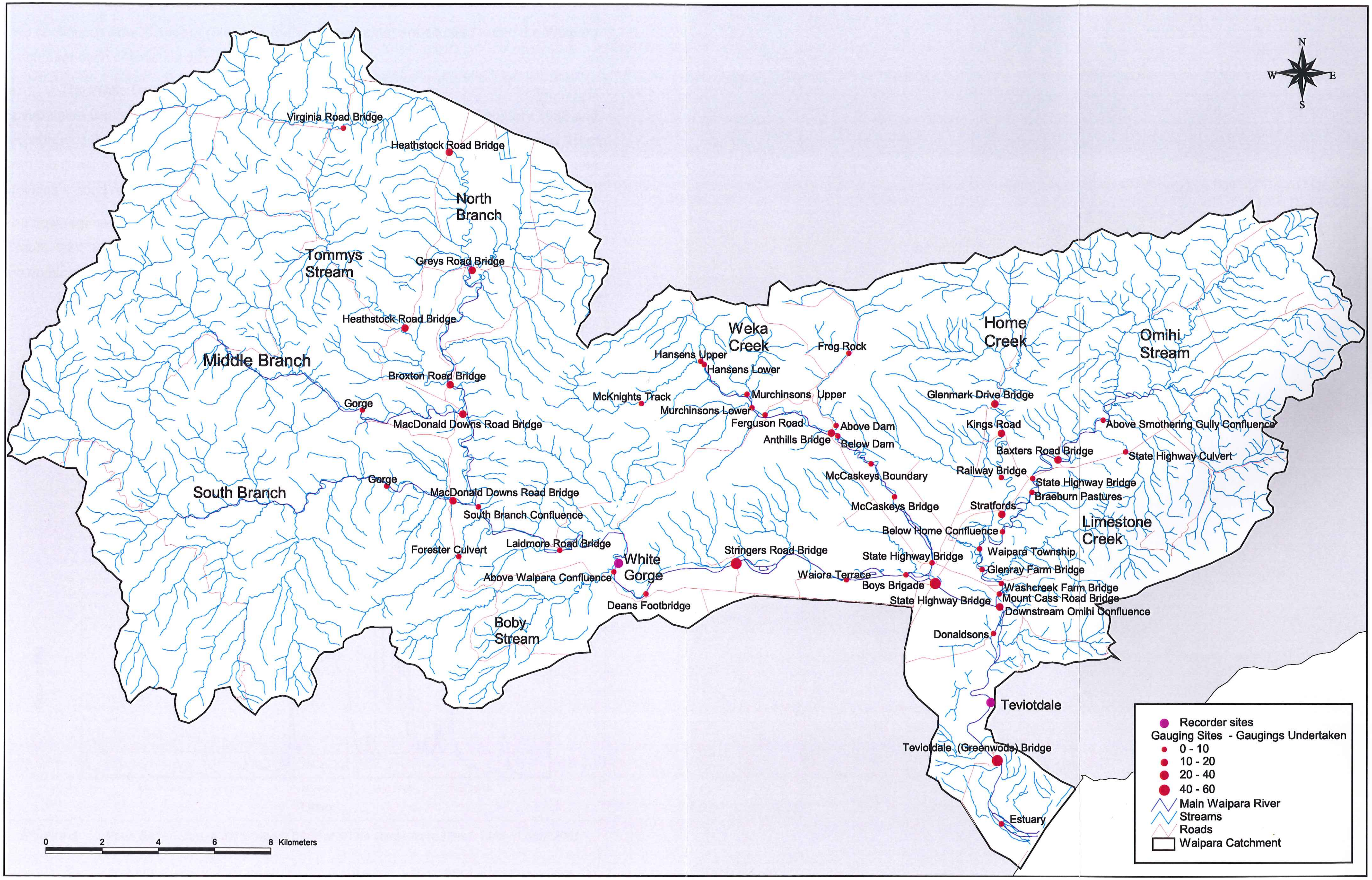


Figure 4-1 ***Surface Water Network and of Flow Measurement Sites, Waipara Catchment.***

4.2.2 CONTINUOUS FLOW RECORDS

Two continuous flow recorders (White Gorge and Teviotdale) are situated within the Waipara Catchment each of which is discussed below.

(a) The White Gorge Flow Recorder

Environment Canterbury's White Gorge flow recorder was established in February 1988 and a continuous flow record is available from that time. The White Gorge site is situated 31km from the coast at approximately the boundary between the upper and lower catchments, and provides a good record of outflow from the upper catchment.

The flow regime is dominated by low flows with occasional large short duration flood events (Figure 4-2). Flood flows usually occur over the winter months whereas the summer months are dominated by very low flows.

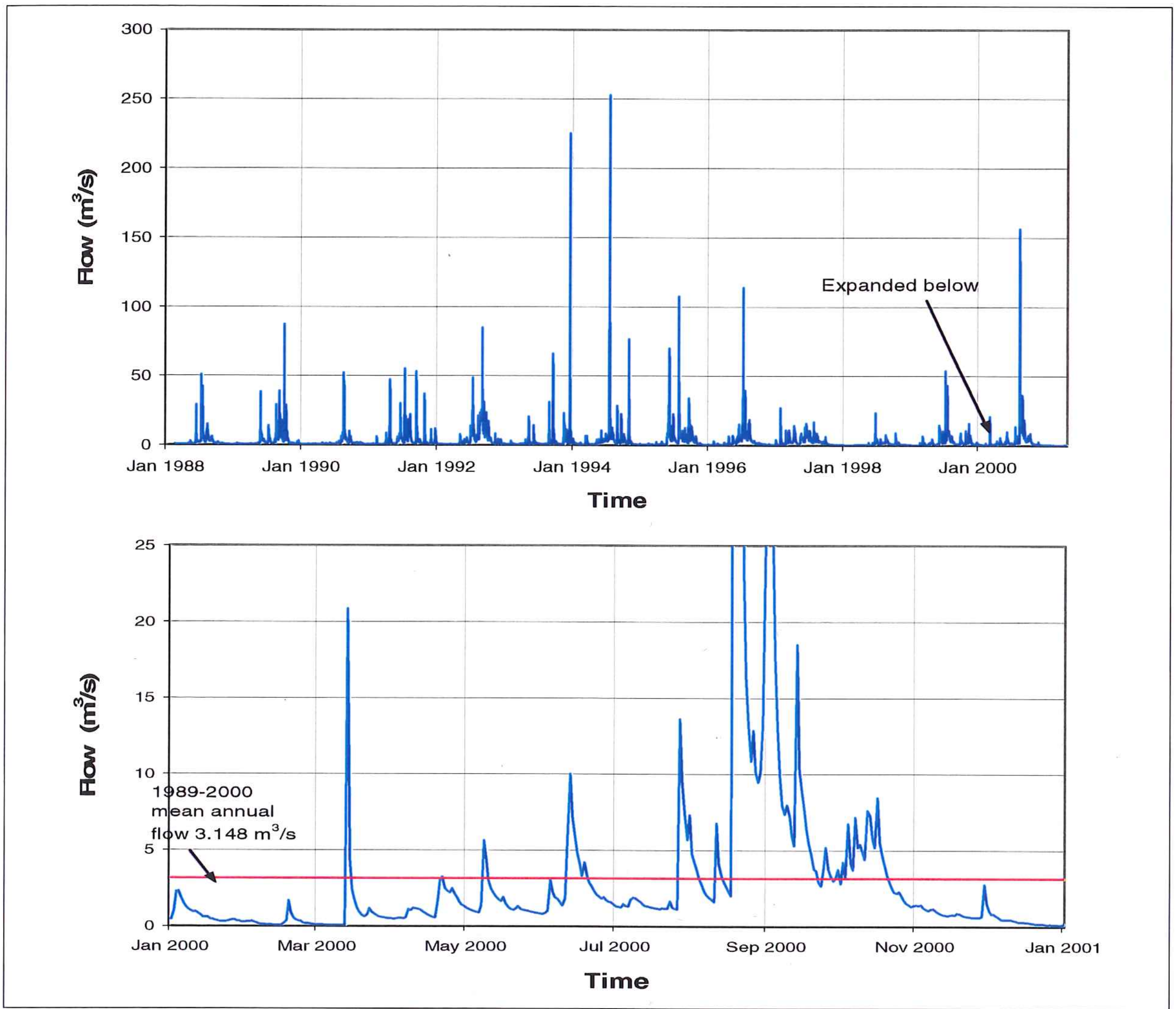


Figure 4-2 ***Mean Daily Flows in the Waipara River at White Gorge from March 1988 to April 2001***

An exceedence plot of flows in the Waipara River at White Gorge is shown in Figure 4-3. At higher flows, the plot is steep indicating a lack of storage (i.e. lakes, dams, wetlands, and snow) in the catchment. The curve rapidly flattens out below flows of 2000 l/s, indicating that flow in the Waipara River is strongly skewed towards low flows. It is noted that while the mean annual flow for 1989-2000 was 3148 l/s, the median flow for the same period was only 984 l/s. The coefficient of variation (CV = standard deviation / mean) for the March 1988 to April 2001 (inclusive) instantaneous flow record is 2.9, which is considered high. Rivers with high CV have flow regimes dominated by long periods of low flow and large infrequent short duration flood events (Clausen et al., 1999). In this regard, flow in the Waipara River is significantly more variable than flows in either the Ashley River to the south (CV=1.6) or the Hurunui River to the north (CV=0.9) (Duncan, 1992). This variability of flow indicates that the flow regime of the Waipara River is dominated by base flow and that the catchment receives irregular precipitation and that groundwater seepage to the river is not significant.

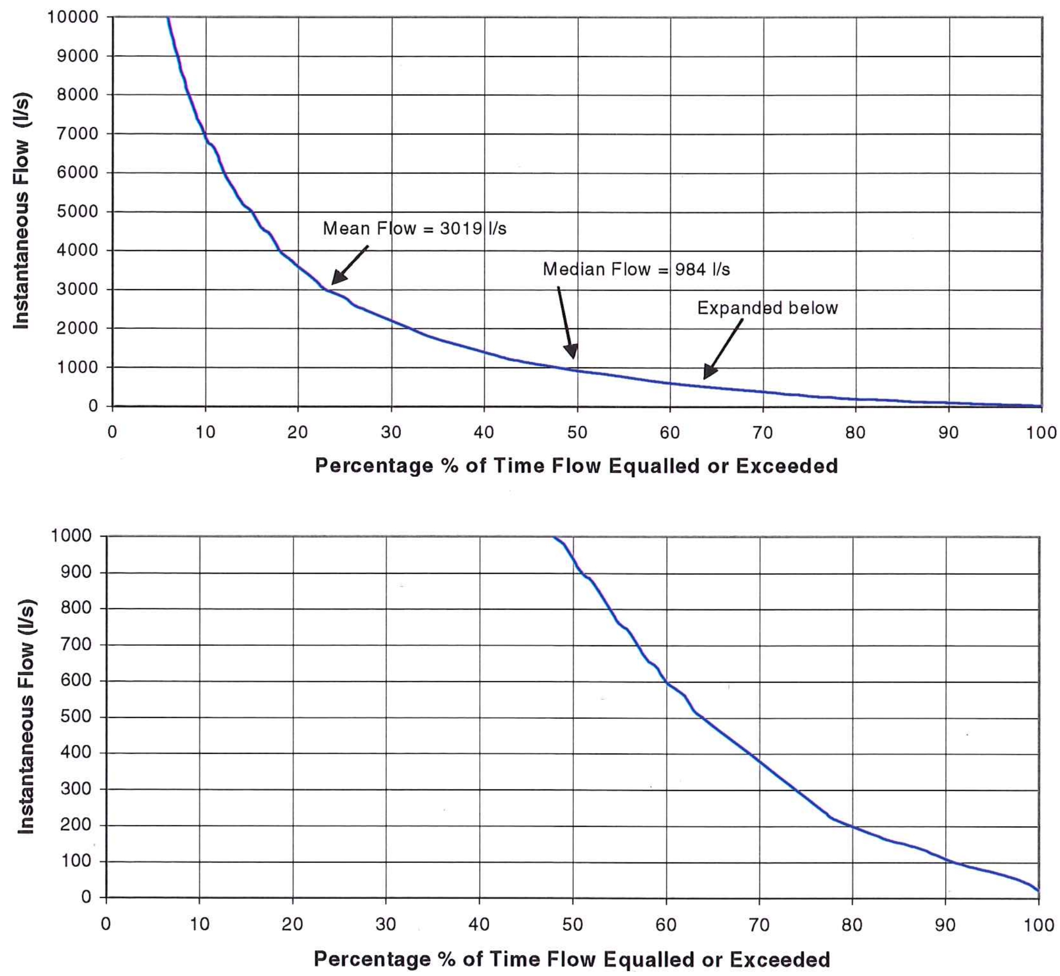


Figure 4-3 ***Flow Distribution (25 February 1988 – 30 April 2001) for the Waipara River at the White Gorge Recorder site.***

Records from White Gorge reveal that the 1989-2000 mean annual flow was 3148 l/s. The flow pattern is strongly seasonal reflecting the effects of evapo-transpiration. Mean monthly flows vary from approximately 520 l/s during January to 7285 l/s during July (Figure 4-4). The 1988-2000 mean flow during the summer irrigation season (November-March) is only 1198 l/s, which coincides with the period when demand for water is at its highest.

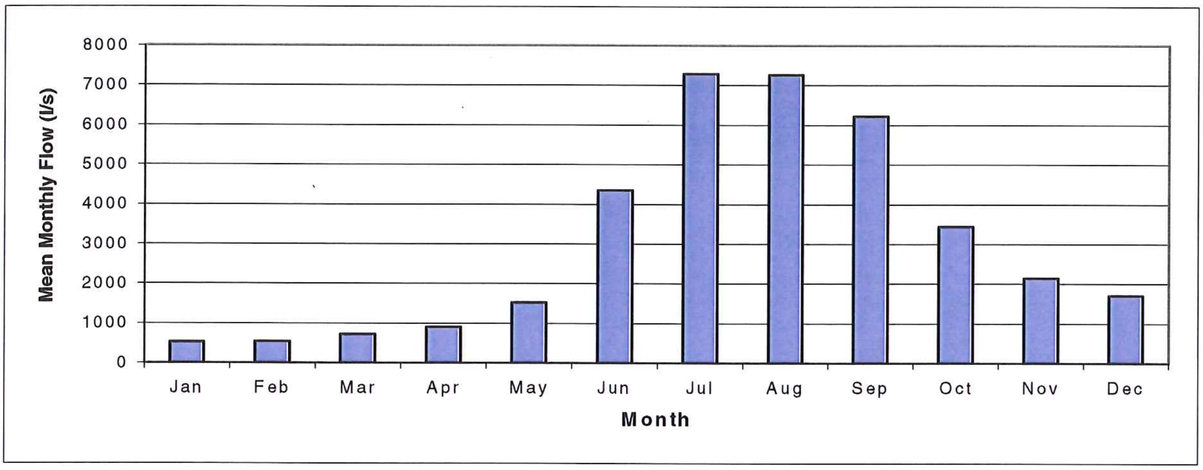


Figure 4-4 ***Mean Monthly Flows (March 1988-April 2001 inclusive) in the Waipara River at White Gorge***

(b) The Teviotdale Flow Recorder

Environment Canterbury established the Teviotdale flow recorder site in April 2000 as a follow up to a study undertaken by NIWA on low flows in the river (Jowett, 1994). The site is currently operated by NIWA who supply a copy of the flow records to Environment Canterbury. The recorder is situated within the lower gorge 7km from the coastline (24 km downstream of the White Gorge recorder. As expected the flow pattern at Teviotdale generally follows the pattern at White Gorge with a six hour lag between the sites Figure 4-5.

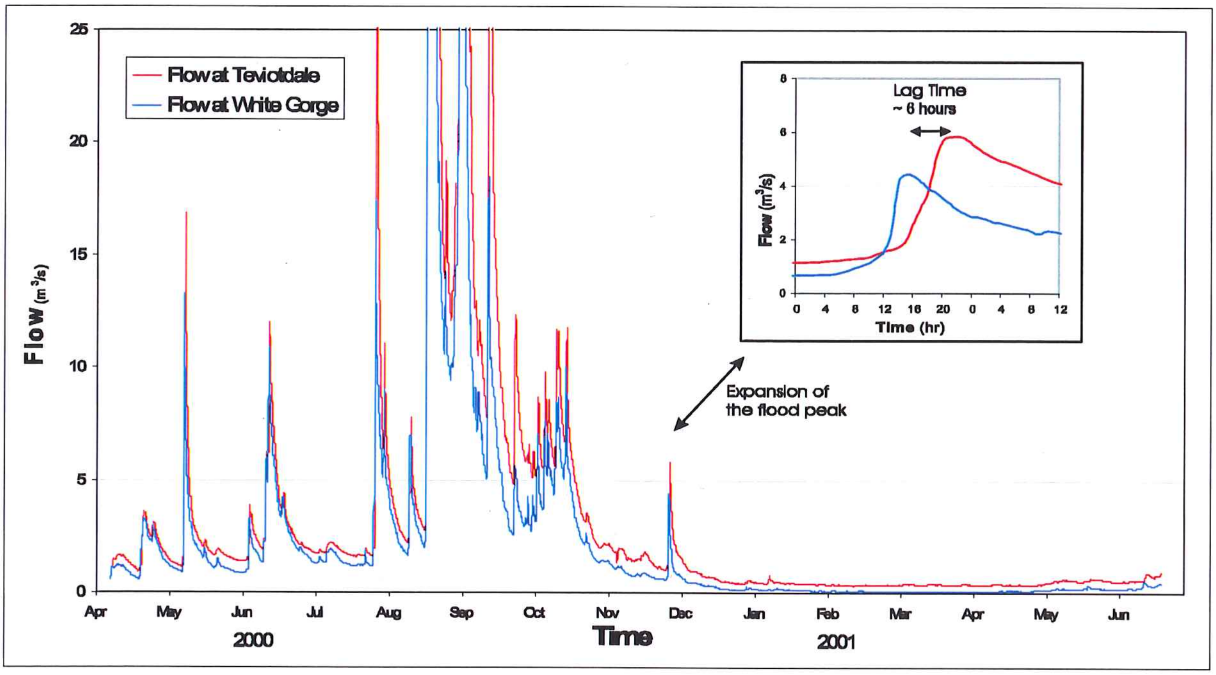


Figure 4-5 ***Mean hourly flows in the Waipara River at the White Gorge and Teviotdale Recorder site, 25 April 2000 to 26 June 2001***

Utilising mean hourly flow data from the recorders and allowing for the 6 hour time lag, a regression relationship was established between the two sites (Figure 4-6). As the flow regime is highly skewed towards low flows, the data was log-transformed prior to undertaking the regression to reduce the affect of extreme values (flood events).

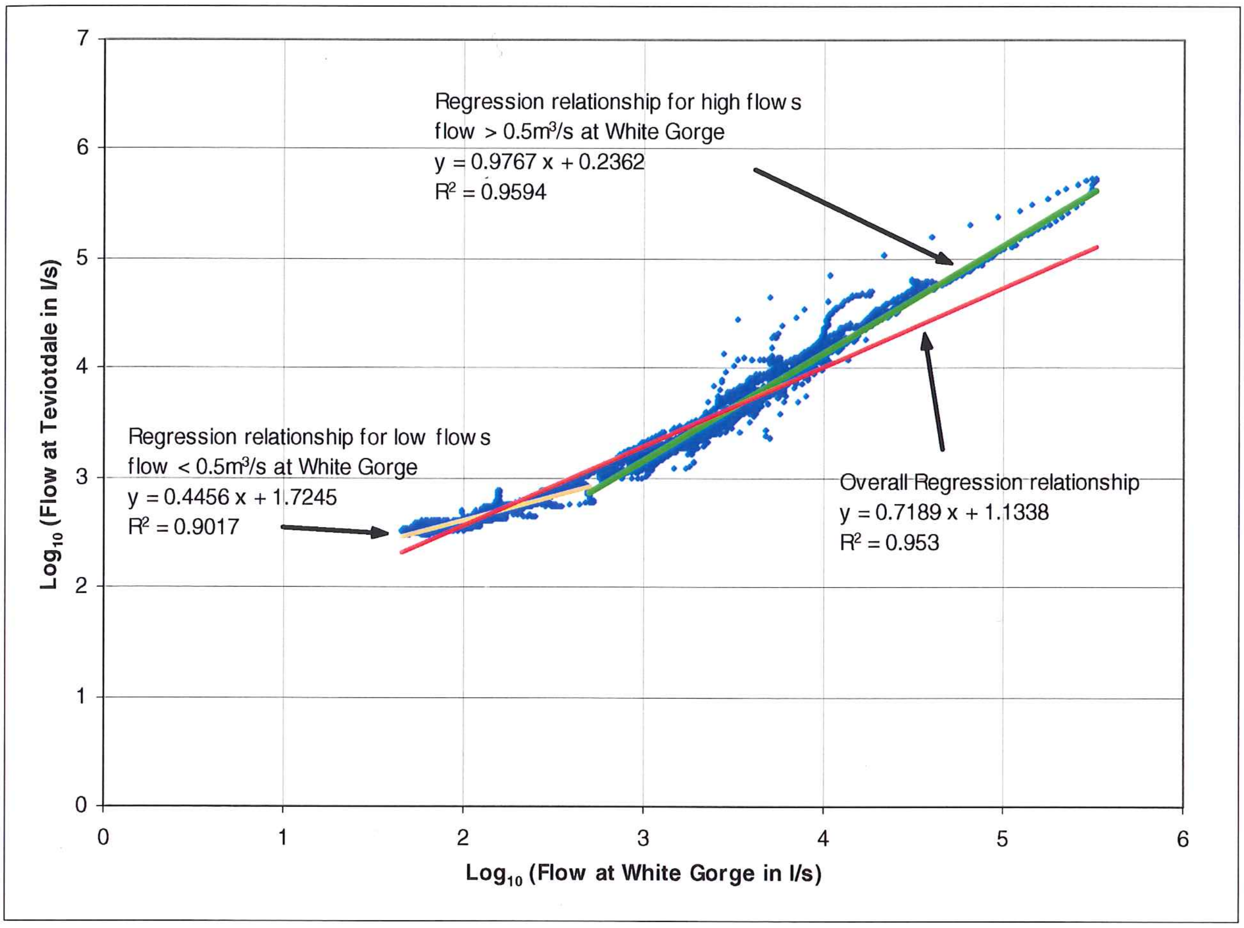


Figure 4-6 ***Regression Relationship between flow in the Waipara River at the Teviotdale and White Gorge Recorder Sites based on flow data from 8 April 2000 to 26 June 2001 (Data included in Appendix 4.1)***

The regression indicates that while flow at the Teviotdale recorder site is strongly related to flow at White Gorge, the nature of the relationship changes during periods of very low flows. For flows at White Gorge of less than 500 l/s, the overall regression relationship tends to underestimate flow at Teviotdale (Figure 4-6). This suggests that at Teviotdale runoff from the lower catchment (presumably from Omihi Stream), makes more of a contribution to flow during periods of low flow than it does during mid to high flows. It is noted that flow at the Teviotdale recorder is affected by upstream irrigation abstractions which would tend to reduce flows. Between 8 April 2000 and 26 June 2001, the lowest instantaneous flow recorded at Teviotdale was 302 l/s. During the same period, mean daily flow at White Gorge was at or below 60 l/s for at total of 25 days. This highlights the significant contribution runoff from the lower catchment makes to flows in the Lower Waipara River.

4.2.3 INSTANTANEOUS FLOW GAUGING RECORDS

At the end of September 2001 some 643 gauging or flow observations had been undertaken within the Waipara Catchment and are included on Environment Canterbury's gauging database. Environment Canterbury and its predecessors have undertaken regular instantaneous gaugings since 1971 in order to rate the White Gorge Recorder site and to access changes in flow along the river. Of the 643 gaugings, 125 were undertaken by the author as part of this study. Additional gaugings have also been undertaken by NIWA to rate the Teviotdale Recorder.

Based on instantaneous gauging data collected in April 2000, Loris (2000) found that the Waipara River was predominantly gaining flow between the Deans Footbridge and the Omihi Stream confluence. Historical gauging data collected by Environment Canterbury supports this conclusion. Unfortunately during many of these gauging runs, flow measurements were undertaken at a limited number of sites and generally did not adequately assess tributary inflow.

(a) Detailed Gauging Runs

To account for deficiencies in earlier investigations, four detailed gauging runs were undertaken along the entire length of the Waipara River and its major tributaries. The aim of the gauging runs was to accurately assess both tributary inflow and groundwater/surface water interactions. Gauging runs were undertaken in September-October 2000, January, April and September 2001 with a total of 125 gauging and flow assessments completed at some 45 sites (Appendix 4.2). The gauging sites were selected at regular intervals and to coincide with historical gauging sites. To reduce the effects of underflow the gaugings were undertaken where the streambed consisted of low permeability geological strata. The gauging runs were scheduled to collect data at times of different soil moisture and ground water levels. September-October coincides with high groundwater levels and the period when groundwater is most likely to recharge the river. April represents low groundwater levels following the irrigation season and the period when river flow is most likely to recharge groundwater. January represents a mid range situation.

The gaugings were undertaken using either a small Ott or Pygmy flow meter, using the 0.6 depth method and the standard river gauging procedures as outlined in the NIWA Stream Gauging Manual (NIWA, 1996). Discharges were calculated using the NIWA software program GAUGE version 3.2 with the results included in Environment Canterbury's gauging database.

(b) Interpretation of Instantaneous Gauging Data

Estimates of discharge found by using the velocity area-method contain an uncertainty of at least 5% (Clausen et al., 1999). The average error in the 125 gaugings undertaken as part of this study was 8.8% as calculated by GAUGE. As such only differences in flow of greater than 10% are considered to indicate gains and losses of flow.

(i) The Main Waipara River

As shown in Figure 4-7, thirteen of the fifteen (12 historical and 3 undertaken by the author) gauging runs indicate that the Waipara River gains flow throughout its length during high flows. The two gauging runs (7-8 March 1984 and 11 June 1991) which indicate the opposite are due to changing flow regimes affecting the gauging data. Daily rainfall data from Glenrose Farm in the Omihi Valley indicated that it rained on 7 and 8 of March 1984 and the gauging data would have been affected by the storm hydrograph. The flow record from the White Gorge flow recorder shows a small flood event occurred during the night of 10 June 1991 and as such the gaugings were undertaken on the falling limb of the storm hydrograph.

During periods of low flow the Waipara River gains flow over most of its length due predominantly to tributary inflow Figure 4-8. The low flow gaugings highlighted two sections of the river where flow is lost. Approximately 20 l/s of flow is lost between the confluence of the Middle Branch and the confluence of the Southern Branch, where the streambed consists of tertiary geological deposits overlain by a thin covering of recent river gravel. The losses are relatively small in size and are therefore not detected at high flow where tributary inflows overshadow the losses.

Below the Teviotdale Bridge significant flow losses occur which coincides with a change in streambed lithology from tertiary deposits to deeper gravel deposits. At low flows, much of the flow seeps into the gravels and the river regularly runs dry (as was experienced in April 2001 Figure 4-9).

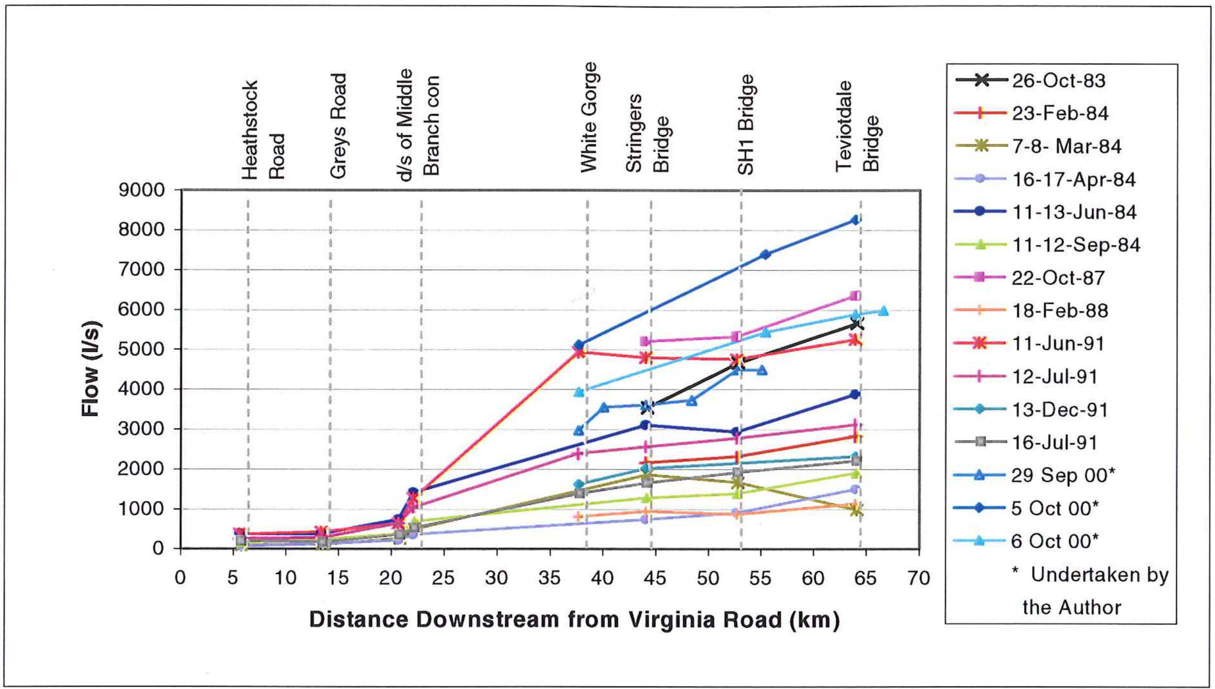


Figure 4-7 ***Plot of Waipara River Flow obtained from various instantaneous gauging runs undertaken during medium to high flow.***

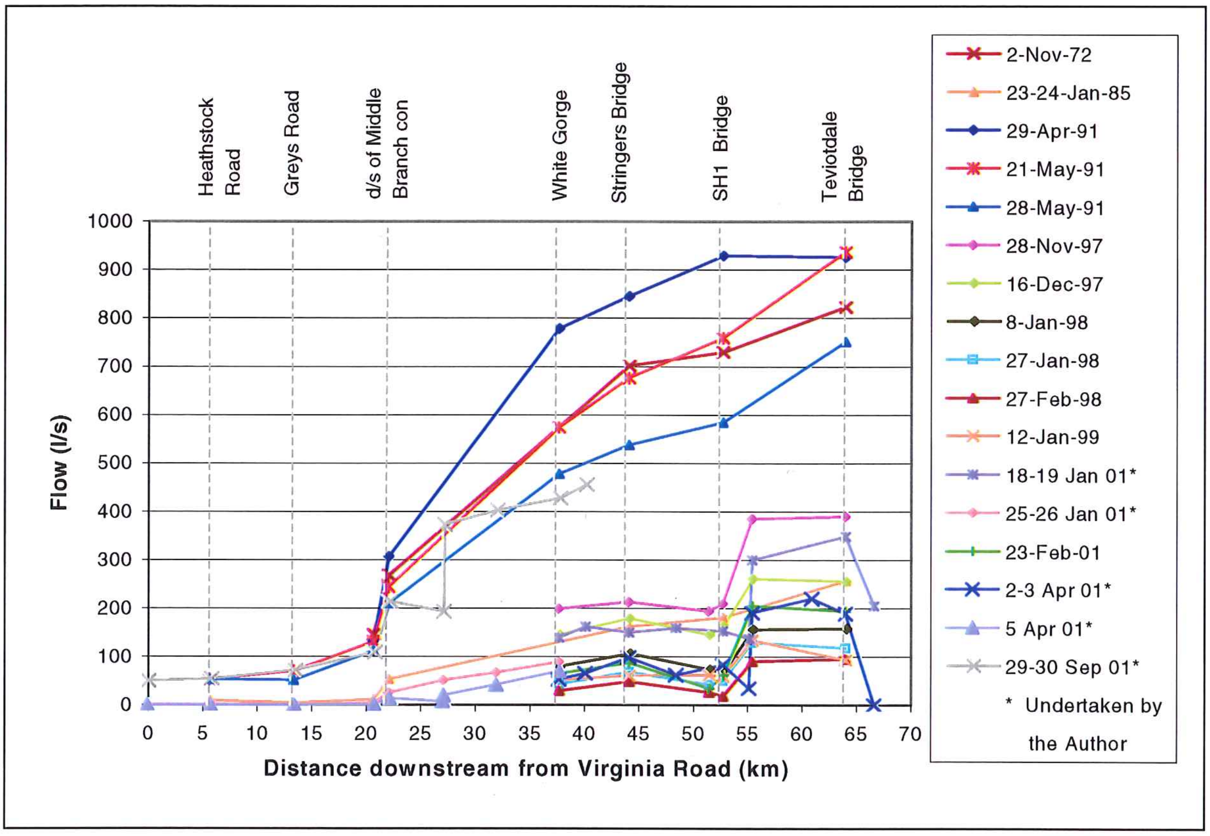


Figure 4-8 ***Plot of Waipara River Flow obtained from various instantaneous gauging runs undertaken during low flows***

Figure 4-9 *The Waipara River at the Estuary Gauging Site (Grid Reference M34:923841) on 3 April 2001, looking upstream.*

At low flows (< 100 l/s at White Gorge), flow in the Waipara River remains fairly constant between the Deans Footbridge and the confluence of the Omihi Stream with only minor fluctuations in river flow which are within the error range of the gauging data.

It is concluded that the surface water in the Waipara River is not significantly connected to the area's groundwater other than below the Teviotdale Bridge and small areas in the Upper Catchment, which is consistent with the findings of Loris (2000).

(ii) Weka Creek

Only four gaugings runs have been undertaken on the Weka Creek, all of which were completed (by the author) as part of this study. Significant flow losses occur below the Glenmark Irrigation Scheme intake structure in (**Figure 4-10**). While there is usually surface flow immediately below the intake structure, surface flow only occurs at the State Highway 7 Bridge during the wet winter months or immediately following large storm events. This loss in flow coincides with a change in streambed lithology from eastward dipping tertiary sandstone and limestone deposits to more recent gravel deposits. The loss in flow is due to seepage into these gravel deposits.

In the upper catchment, the 28 September 2001 gauging run indicates Weka Creek loses a small amount of flow immediately above the Ferguson Road Bridge where the creek flows over tertiary geological strata (**Figure 4-10**). Through this section the streambed consists of limestone beds and sandstone beds which dip downstream towards the east. It is suspected that the loss of flow is due to flow into a more permeable bed within the tertiary deposits, possibly a limestone or gravel bed.

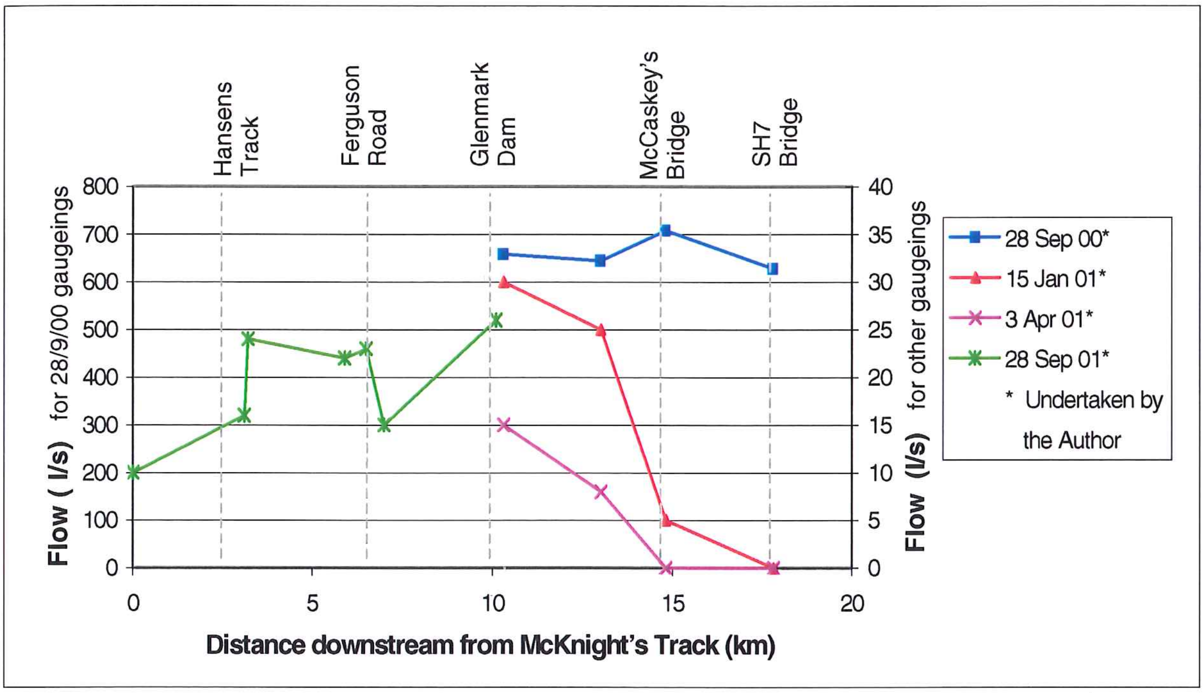


Figure 4-10 Plot of Weka Creek flow obtained from various instantaneous gauging runs

(iii) Omihi Stream and Home Creek

All 10 gauging runs (7 historical and 3 by the author) undertaken on Omihi Stream show a marked increase in flow immediately above the Glenray Farm Bridge (Figure 4-11). This increase is almost certainly a result of the numerous springs in this area identified by Loris (2000) and the increase in flow is due to spring discharges. The detailed gauging run undertaken on 10 October 2000 indicated that flow was lost between Baxters Road Bridge and Braeburn Pastures. The lack of gaugings undertaken at either the Braeburn Pastures or the State Highway 1 Bridge sites prevent verification of this loss in flow which could be the result of gauging errors.

All 12 gauging runs (9 historical and 3 by the author) undertaken, show that Home Creek gains flow between Glenmark Drive and Kings Road and then loses flow downstream of Kings Road (Figure 4-12). A number of large high yielding springs exist behind the Glenmark Homestead (Loris, 2000) and the increase in flow between Glenmark Drive and Kings Road is due to spring discharges. Home Creek loses flow below Kings Road during all the flow regimes measured and represents seepage into gravel deposits.

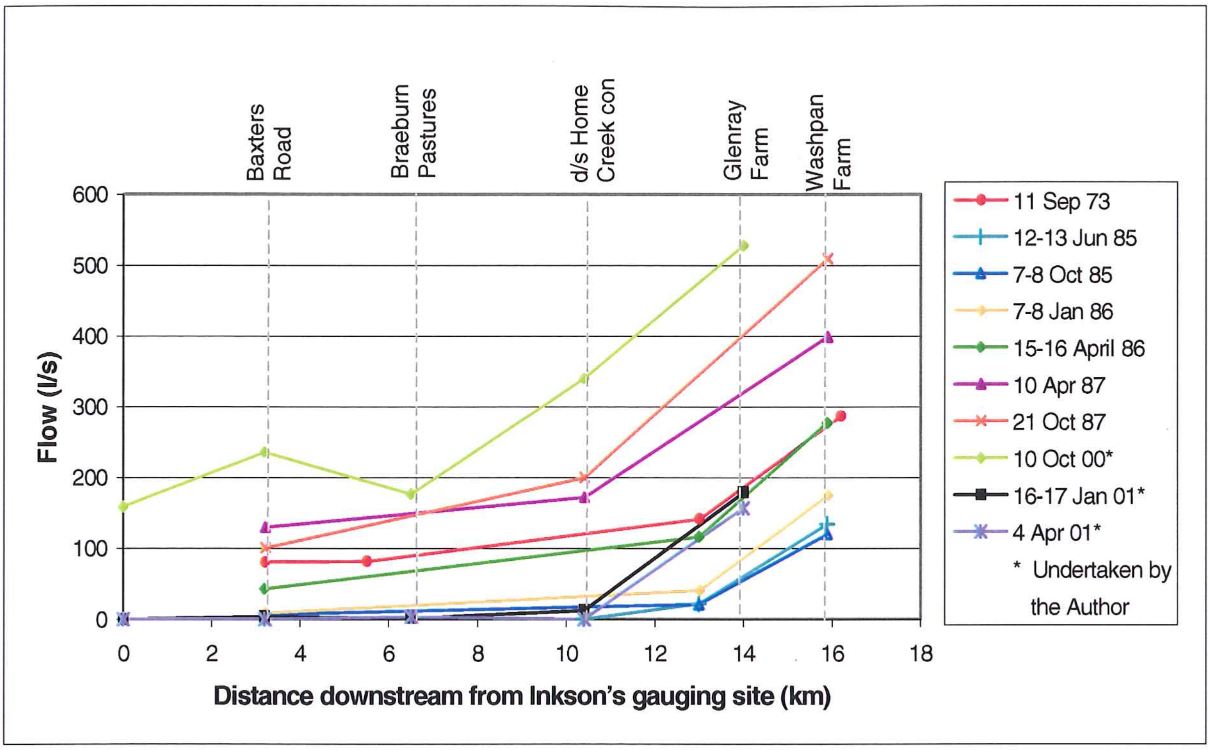


Figure 4-11 ***Plot of Flow in Omihi Stream obtained from various instantaneous gauging runs***

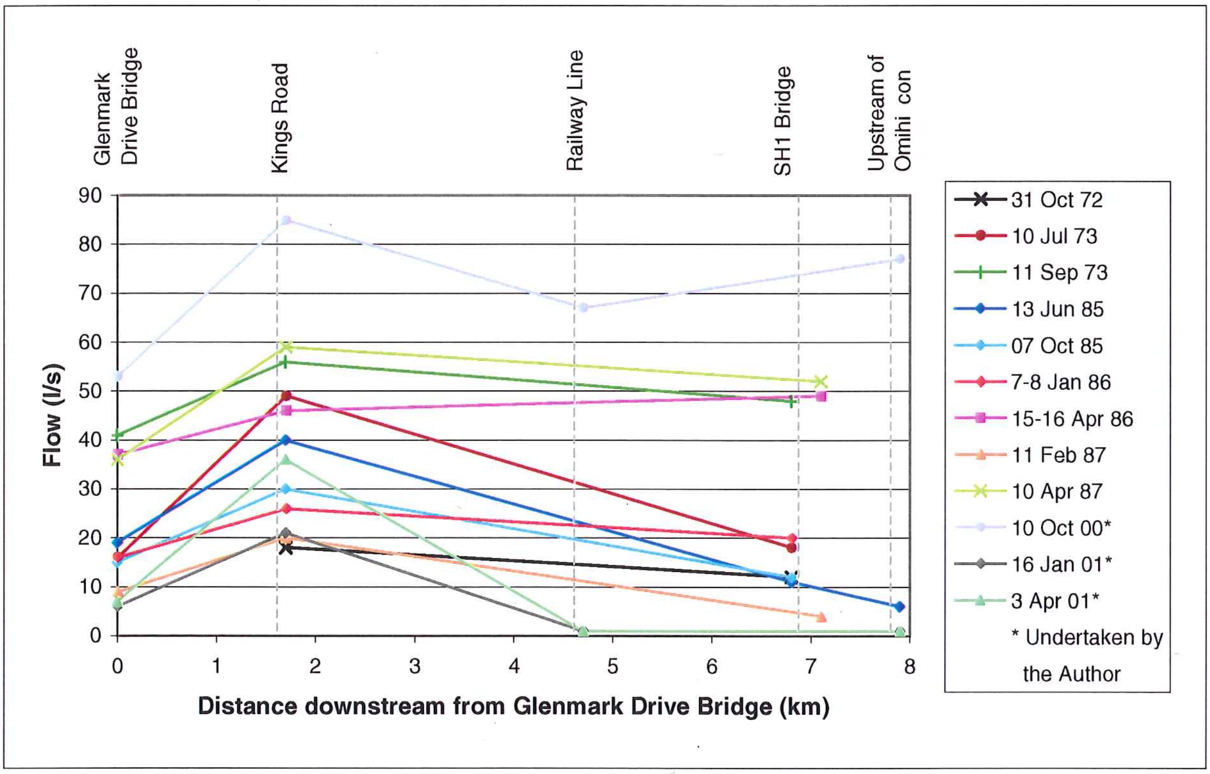


Figure 4-12 ***Plot of Flow in Home Creek obtained from various instantaneous gauging runs***

4.2.4 FLOW AT VARIOUS SITES ALONG THE WAIPARA RIVER

The flow data from both the recorders and the instantaneous gauging runs, allowed a regression relationship to be developed between flow at White Gorge and various other sites along the Waipara river (Table 4-1 and Appendix 4.3). As most of the flow gaugings were undertaken at low flow, the flow data was log transformed to reduce the affect of extreme values. The regressions indicate that the South Branch contributes most of the flow from the upper catchment and that the Waipara river gains flow over most of it's length (Table 4-1).

Table 4-1 1989-2000 Mean Annual Flows (l/s) at various sites along the Waipara River

Site Name	Mean Annual Flow (l/s)	Distance from mouth (km)	Regression Equation $W = \text{Log}_{10}$ (Flow at White Gorge in m^3/s)	Coefficient of Determination R^2	Number of Observations N
North Branch and Tommy Stream	620	48	0.8491 W – 0.6336	0.86	12
Middle Branch	520	47	0.8791 W – 0.7198	0.95	15
South Branch	1130	42	0.946 W – 0.4198	0.97	15
White Gorge	3148				
Stringers Bridge	3350	24	0.9483 W + 0.0522	0.99	34
S.H.1 Bridge	3890	15	1.0472 W + 0.0688	0.98	20
Downstream of the Omihi Confluence	4480	13	0.8659 W + 0.2199	0.95	14
Teviotdale Recorder	4500	7	0.4456 W* + 1.7245 Low Flow 0.9767 W* + 0.2362 High Flow	0.90 0.96	Continuous
Teviotdale Bridge	3750	4	0.8174 W + 0.1674	0.96	30

* = Log_{10} (Flow at White Gorge in l/s)

4.2.5 LOW FLOWS

The flow regime of the Waipara River is dominated by long periods of low flows. The lack of storage within the catchment and the hot dry climatic conditions during the summer lead to very limited flows. The 1989-2000 mean annual instantaneous low flow at White Gorge is only 70 l/s with a lowest flow reading of only 23 l/s being recorded in February 1998. The 1989-2000 mean annual 7-day low flow is 88 l/s. It is noted that during the period March 1988 to April 2001, mean daily flow has dropped below 88 l/s on 200 occasions, with such flows occurring on average 11 times per year (Table 4-2). Over the same period the 7-day mean flow has dropped below 88 l/s for a total of 28 weeks.

Table 4-2 Daily low flow of less than 88 l/s recorded at White Gorge, March 1988-April 2001.

Year	1988*	89	90	91	92	93	94	95	96	97	98	99	2000	2001*	Average 1989-2000
Number of days daily flow < 88 l/s	9*	16	11	6	-	-	-	-	3	1	62	29	8	55*	11

* part year only, 1988 March-December, 2001 January-April

For management reasons, Environment Canterbury have established the following minimum flows (i.e. flows below which abstraction of water is not allowed) for the Waipara River.

White Gorge	50 l/s
Stringers Bridge	60 l/s
Teviotdale (Greenwoods) Bridge	80 l/s

Analysis of the flow record at White Gorge reveals that during the period March 1988 to April 2001, mean daily flow has dropped below 50 l/s on 67 occasions. It is noted that 62 of these low flows occurred during the dry summers of 1989 and 1999. Low flows do not usually persist for long periods of time, although it is noted that the 7-day mean flow has dropped below 50 l/s at White Gorge for a total of 9 weeks between March 1988 and April 200.

4.2.6 HIGH FLOWS

While the flow regime of the Waipara River is dominated by periods of low flow, significant floods occur due to high intensity rainstorm events that infrequently affect the catchment. The highest instantaneous flow recorded at White Gorge is 329 cumecs in August 2000. The 1989-2001 mean annual instantaneous high flow at White Gorge was 134 cumecs. The floods themselves (while having relatively high peaks) are of short duration and the mean 1989-2000 7-day high flow is only 35.0 cumecs.

During the period March 1988 to April 2001 mean daily flow at White Gorge exceeded 20 cumecs on 89 days, with such flows occurring on average 7 times per year (Table 4-3). High flows do not usually persist for long periods although over the same period the 7-day mean flow exceeded 20 cumecs 18 times.

Table 4-3 Daily Flood flows of greater than 20 m3/s recorded at White Gorge, March 1988-April 2001.

Year	1988*	89	90	91	92	93	94	95	96	97	98	99	2000	2001*	Average 1989-2000
Number of days flow > 20 m^3/s	4*	9	4	10	15	9	9	9	6	1	2	4	7	-*	7

* part year only, 1988 March-December, 2001 January-April

4.2.7 FLOW CONTRIBUTIONS AND CATCHMENT RUNOFF

As outlined in Section 4.2.4, there is good correlation between flows at various sites along the lower Waipara River, namely Stringers Bridge, State Highway 1 Bridge and below the Omihi confluence. Weka Creek joins the Waipara immediately upstream of the State Highway 1 Bridge and most of the change in flow of the Waipara River between Stringers Bridge and the State Highway 1 Bridge can be attributed to inflow from the Weka Creek. Similarly, the difference in flow between downstream of the Omihi Stream confluence and the State Highway Bridge can be attributed to inflow from Omihi Stream (including Home Creek and Limestone Creek). Based on the above, Table 4-4 summarises runoff from the various sub-catchments of the Waipara River.

Table 4-4 1989-2001 Runoff from sub-catchments of the Waipara River

	Upper Catchment	**Weka Creek***	**Omihi Stream and Home Creek**	**Total Catchment to the Teviotdale Recorder**
Mean Annual Flow l/s	3148	540	590	4500
Area of Catchment km^2	333.5	96.7	175.8	701.2
Runoff $l/s/km^2$	9.4	5.6	3.4	6.4
Runoff mm/yr	298	176	106	202

* Includes catchment between Stringers Bridge and the State Highway 1 Bridge

Runoff for the catchment (6.4 $l/s/km^2$) is very low and is significantly less than both the Ashley River to the south (10.8 $l/s/km^2$) and the Hurunui River in the north (20.3 $l/s/km^2$), and is more comparable to the dry Hakataramea River in Otago (6.7 $l/s/km^2$) (Duncan, 1992). The variation of runoff from the various sub-catchments highlights differing precipitation, topography, soil type and geology. The catchment runoff values calculated above are similar to Horrell (1992) who found average (1961-1990) annual catchment runoff to be 6.83 $l/s/km^2$ for the upper catchment, 5.97 $l/s/km^2$ for Weka Creek and 1.12 $l/s/km^2$ for Omihi Stream. The low catchment runoff for the Omihi Stream suggests that water may be leaking out of the catchment presumably through the Tertiary rock units which dominate the geology of the Omihi Stream sub-catchment.

Analysis of the detailed gauging undertaken indicates that during low flows, the Southern and Middle Branches contribute approximately 60% and 20% respectively of the flow at White Gorge. The remaining 20% comes from various small tributaries downstream of the Southern Branch confluence. During low flow neither Tommys Stream nor the North Branch contribute significantly to the flow at White Gorge.

The September 2001 gauging run suggests that at medium to high flow the Southern, Middle and Northern Branches and Tommys Stream contribute approximately 40%, 20%, 15% and 10% respectively of the flow at White Gorge. The remaining 15% is made up of inflow from various small tributaries particularly those below the Southern Branch confluence.

The gauging runs undertaken during January and April 2001 indicated that Omihi Stream provided 40% and 70% of the flow at the Teviotdale recorder. It is concluded that during periods of low flow approximately 50% of the flow exiting the Waipara catchment at the

Teviotdale recorder is derived from the Omihi Stream and more specifically the springs which are situated immediately upstream of the Glenray Farm Bridge.

During periods of high flow, runoff from the upper catchment becomes dominant due primarily to the increased precipitation that the upper catchment receives (Chapter 3). Flow data from the White Gorge and Teviotdale recorders (Section 4.2.2) indicates that 3148 l/s or 70% of the 1989-2000 mean annual flow at the Teviotdale Recorder (4500 l/s) is derived from upstream of White Gorge.

4.2.8 EXISTING USE

Historically, domestic and stock water requirements were met from a combination of tapping springs, runoff storage in small stock dams, abstractions from the area's creeks and rivers, numerous shallow wells and a limited number of deeper boreholes. Since the establishment of the rural water supply schemes in the 1960-70s, many of these individual farm water sources have been abandoned and large sections of the catchment now rely on the rural water supply schemes.

Irrigation in the Waipara Basin dates back to the early 1950s when the first significant abstractions of water from Omihi Stream and Home Creek commenced. The establishment of the Glenmark irrigation scheme which utilises flows in Weka Creek, Home Creek and Omihi Stream in the late 1970s early 1980s, heralded the start of increased irrigation activity in the area. Since 1990, significant land development in the area has lead to an ever increasing demand for irrigation water. To date much of this demand has been satisfied by abstractions from the main Waipara River and more recently from groundwater abstractions.

At the 1 June 2001, the Environment Canterbury consents database contained 30 current consents authorising the abstraction of surface water or hydraulically connected groundwater from the Waipara Catchment (Table 4-5 note one of the consents is actually a groundwater take but is wrongly classified in the consent files). Fifteen of the consents are for abstractions from the main Waipara River (one is currently subject to an Appeal), 7 from Omihi Stream (one is for an abstraction from a spring in the catchment), 5 from Home Creek and one from Weka Creek. There are a further 11 water permits to dam and 3 to divert water. All except two of the consents are for irrigation either directly (16) or indirectly (10) via storage.

Table 4-5 Current Water Permits in the Waipara Catchment as at 1 June 2001
(Summarised from Environment Canterbury's consent files)

Permit Holder	Consent Number	Max. Rate l/s	Max. Daily m^3	Purpose	Expiry Date
Surface Water Takes					
Home Creek					
Glenmark Homestead	CRC011833	15	7560	Storage spray irrigation pasture/crop*	2036
Glenmark Homestead	NCY800618A	15	910	Spray irrigation pasture/crop	2001
Gould D.C.	CRC920808B	55	4752	Spray irrigation pasture/crop	2004
Hutt Creek Vineyards Ltd	CRC920812B	40	3456	Storage trickle irrigation grapes	2004
McGuckin D.J.	CRC920820	4	160	Spray irrigation pasture/crop	2004
Omihi Stream				* replaces Consent NCY800618A	
Corbins Wines Ltd	CRC920816A	45	3888	Storage trickle irrigation grapes	2004
Dickie M.R. & C.A.	NCY850184	31		Spray irrigation pasture/crop	2001
East M.C.	CRC920699B	2	138	Storage trickle irrigation grapes	2004
Glenray Farming & Chancellor	CRC920817B	25	2160	Storage spray irrigation pasture/crop	2004
Savill E.M.	CRC916346B	1	120	Storage trickle irrigation grapes	2004
Stackhouse K.W.	CRC920814B	45	3888	Storage spray irrigation pasture	2004
Stackhouse K.W.	NCY800639	40	3490	Spray irrigation pasture/crop	2001
Waipara River					
Canterbury House Vineyard	CRC940238	26	2280	Trickle irrigation of grapes	2029
Chapman B.A.	CRC000546	8	222	Spray irrigation	2004
Croft W.H. & R	CRC920476	31	1318	Spray irrigation pasture/crop	2004
Donaldson I.M & C.C	CRC920345A	12	605	Trickle irrigation of grapes	2004
Donaldson I.M & C.C	CRC920345B	45	1300	Winter frost protection grapes	2004
Hurunui Distict Council	NCY800745[2]	12	1307	Waipara Public Water supply	2001
Johns B.S.	CRC940475	13	1080	Storage trickle irrigation grapes	2004
Litchfield Nominees No 14 Ltd	CRC010463	13	1080	Storage trickle irrigation grapes	2035
Maungatahi Farms	CRC920587	50	4320	Spray irrigation pasture/crop	2004
Maungatahi Farms	CRC950255	38	3283	Spray irrigation pasture/crop	Appealed
Maungatahi Farms	NCY840049	22	978	Spray irrigation pasture/crop	2001
Rangatahi Downs Ltd	CRC920588	38	3280	Spray irrigation pasture/crop	2004
Retallick T.E. & M.C.L.	CRC920650	15	432	Trickle irrigation of olives	2004
Stewart R.G.	CRC992263	110	8578	Trickle irrigation of grapes	2034
Williams G.E.D.	CRC920790	45	1944	Spray irrigation pasture/crop	2004
Renowden G.	CRC992499[1]	1	86	Trickle irrigation of trees	2034
Tutton, Sienko and Hill	CRC920498[1]	22	1920	Trickle irrigation grapes	2004
Weka Creek					
Whyte A.E. and others	CRC920803C	820	70848	Storage spray irrigation pasture/crop	2004
Diversions					
Donaldson I.M. & C.C. (Waipara)	CRC970511	<50% of flow		Trickle Irrigation/Forest Protection	2004
Savill E.M (spring Omihi Catchment)	CRC916346A	1	120	Storage trickle irrigation grapes	2004
Whyte A.E. & others (Weka Creek)	CRC920803B	1020	88128	Storage irrigation pasture/grapes	2004
Dams		Volume Ml			
Home Creek					
Glenmark Homestead	NCY800618B	0		Storage spray irrigation pasture/crop	2001
Gould D.C.	CRC920808A	120		Storage spray irrigation pasture/crop	2027
Hutt Creek Vineyards Ltd	CRC920812A	86		Storage trickle irrigation grapes	2027
Omihi Stream					
East M.C.	CRC920699A	0		Storage trickle irrigation grapes	2004
Glenray Farming & Chancellor	CRC920817A	94		Storage spray irrigation pasture/crop	2027
Stackhouse K.W.	CRC920814A	0		Storage spray irrigation pasture/crop	2027
Waipara River					
Donaldson I.M & C.C	CRC952351	0.35		To enhance Wetlands	2030
Penhaligon Holdings Ltd (spring)	CRC000719	0		Water storage	2035
Weka Creek					
Carson W.J. & E. A.	CRC920804A	78		Water storage	2027
Harris B.C.	CRC920806A	60		Storage spray irrigation pasture/crop	2027
Whyte A.E. and others	CRC920803A	Intake		Glenmark Irrigation Scheme intake	2027

[1] Abstractions from hydraulically connected groundwater are considered surface water takes [2] Is a groundwater take

Interviews undertaken with the consent holders revealed that 11 of the consents were not exercised over the 2000-2001 year for the following reasons:

- 3 consents are now covered by groundwater abstractions;
- 3 consents have been replaced by new consents;
- 3 consents are relatively old and have not been exercised for some time;
- 1 consent is subject to an Appeal and has not been exercised as yet, and
- 1 consent is a renewal of three consents, which cannot to be exercised in conjunction with the three earlier consents.

A review of Environment Canterbury's consent files revealed that 1502 l/s has been allocated from the Waipara Catchment, 76% of which is for winter activities e.g. water storage (Table 4-6). The large number of consents that were not exercised during 2000-2001 is highlighted by the fact that while 379 l/s is allocated out of the Waipara River, only consents covering a total of 203 l/s were actually exercised.

Table 4-6 ***Abstraction Rates allocated by all the consents in the Waipara Catchment and those exercised during the 2000-2001 irrigation season and the winter of 2000.***

Tributary	Total flow Allocated (l/s)		Flow Allocated to Winter Activities e.g. Storage (l/s)		Flow allocated to Direct Irrigation (summer) (l/s)	
	All consents	Consents exercised 2000-2001*	All consents	Consents exercised 2000-2001*	All consents	Consents exercised 2000-2001*
Home Creek	114	114	95	95	19	19
Omihi Stream	189	118	118	118	71	0
Weka Creek	820	820	820	820	-	-
Waipara River	379	203	109	58	270	145
Total Catchment	1502	1255	1142	1091	360	164

* Information obtained from interviews with consent holders

The majority of the consented abstractions from the Waipara's lower tributaries (Home Creek, Omihi Stream and Weka Creek) are for water which is taken at higher flow (typically over the winter months) and diverted into storage dams for use over the summer. Contrary to this, the majority of the consented abstractions from the Waipara River are for water which is taken during the summer for direct irrigation.

In regard to the consents that cover irrigation abstractions, actual water use is directly influenced by climate. Precipitation records from both the Glenrose rain-gauge (upper Omihi Valley) and the Stackhouses rain-gauge (Lower Omihi Valley), indicate that while the 2000 spring was significantly wetter than average, the irrigation season from November to March was very dry (Table 4-7). The wet spring delayed the start of the summer irrigation season, while the lack of rain in autumn 2001 resulted in an extension of the irrigation season.

Interviews indicated that water users considered the 2000-2001 summer to be fairly typical in-terms-of water use.

Table 4-7 Precipitation over the 2000-2001 Summer Irrigation Season

Month	Monthly precipitation at the Stackhouse rain-gauge lower (Southern) end of Omhi Valley			Monthly Precipitation at the Glenrose rain-gauge upper (northern) end of Omhi Valley		
	Average 1951-2000 mm	2000-2001 season mm	% of Average	Average 1951-2000 mm	2000-2001 season mm	% of Average
August	74.6	263.9	353	65.7	148.0	225
September	53.5	104.9	196	48.1	89.0	185
October	55.4	47.8	86	52.7	43.5	83
November	57.9	77.7	133	51.0	63.5	125
December	63.7	9.1	14	58.9	5.8	10
January	53.3	26.7	50	49.8	20.0	40
February	52.8	14.0	27	48.0	9.0	19
March	68.6	12.7	19	64.3	6.0	9
April	62.8	12.4	20	56.3	13.5	24
Summer Total (Nov-Mar)	296.3	140.2	47	272.2	104.3	38

Landowner interviews undertaken as part of this study identified 23 properties which abstract stock, domestic and small scale irrigation water from the Waipara River and its tributaries. These abstractions are covered by the Environment Canterbury's current bylaws which permit the abstraction of small quantities (up to 10 cubic meters per property per day) of surface water (Environment Canterbury, 2000a).

Overall, river flows in the Waipara catchment are highly utilised particularly during the summer irrigation season. Recent irrigation developments in the catchment have tended towards utilising either groundwater or harvesting of high winter flows into on-farm storage dams. It is noted that the last major consent for water abstraction from the catchment (Consent Number CRC992263) resulted in a hearing of the Environment Court. The Environment Court decision stated that the evidence presented indicated that:

> *'...the water resources of the Waipara River are heavily allocated to abstractive users with potential abstraction rates exceeding the normal summer supply.'* (RMA W100/95, 1995)

4.3 FLOW MODEL FOR FLOWS IN THE WAIPARA RIVER

4.3.1 INTRODUCTION AND PREVIOUS WORK

To allow an annual water balance to be completed for the period 1951-2000, it is necessary to determine surface water flows out of the catchment for this period. As flow records at White Gorge only extend back to 1988, it was necessary to extend the flow record using a rainfall runoff model.

As part of the development of the Glenmark Irrigation Scheme, Heiler (1977) used a runoff model developed by Taylor (1971) and subsequently modified by Harrington (1976), to determine flows out of the Weka creek from 1931-1972. The model operated a Thornthwaite daily water balance (Thornthwaite et al., 1955) linking precipitation, evapo-transpiration and soil moisture to flow in the stream. The model was found to underestimate flow by 15-20% and was used as a conservative estimate of flow for the design of the Glenmark Irrigation Scheme.

Horrell (1992) developed a linear regression model linking mean monthly flow in the Waipara River at White Gorge to flow in the Ashley River at Ashley Gorge, precipitation at four rainfall stations (Melrose, Masons Flat, Glenallen, and Amberley) and pan evaporation measurements at Lincoln College. Horrell developed seasonal models and achieved good correlation ($R^2 < 0.91$). However it was noted that the model was based on only four years of flow data 1988-1991. The aim of this section is to use the increased flow records to refine Horrell's regression model and thereby extend the flow record.

4.3.2 MODEL METHODOLOGY AND RESULTS

Two multi-linear regression models were developed using the Systat9 computer package. The first model related flow at White Gorge with flow in the neighbouring Ashley River at Ashley Gorge, while the second model related flow at White Gorge to precipitation and evapo-transpiration data.

The flow record at White Gorge provides twelve mean annual flow readings (1989-2000). In order to make the model as simple as possible and to minimise errors, it was considered appropriate to limit the number of variables in each model to three or less. A total of ten variables (annual precipitation at seven sites, annual evapo-transpiration from two sites and mean annual flow in the Ashley River at Ashley Gorge) were utilised with various combinations trialed.

It was found that mean annual flow at White Gorge is strongly related to flow in the Ashley River (R^2 = 0.88) suggesting that the two catchments have similar annual runoff characteristics. Mean annual flows are not strongly related to precipitation at any one particular site (with R^2 ranging from 0.4 to 0.7); however flows have a strong relationship to combined precipitation data from four sites (H22941 Melrose, H22961 Glenallen, H32061-71 Sandhurst and H32072 Whytes) (R^2 = 0.85). This highlights the often very localised nature of storm events in the catchment as discussed in Chapter 3. Annual flows are only slightly related to annual evapo-transpiration (R^2 < 0.3) indicating that low flows during the summer (due to high evapo-transpiration rates) have a limited effect on annual flow and that flood events have a dominant influence over mean annual flow. Table 4-8 below summarises the two models and a full description of the models is given in Appendix 4.4.

Table 4-8 Model Parameters for Mean Annual Flow of the Waipara River at White Gorge

Model	Variables Used	Formula	R^2	Standard Error l/s
Flow	F_A = Mean annual in the Ashley River at the Ashley Gorge P_T = Combined Annual Precipitation at sites H22941 Melrose, H22961 Glenallen, H32061-71 Sandhurst and H22871 Balmoral. E_A = Annual Priestley Taylor evapo-transpiration at site H32322 Ashley Forest taken as a negative number	$F_{Waipara} = 0.266 \times F_A + 1.142 \times P_T - 6.702 \times E_A - 7296.75$	0.964	227.0 Standard Deviation of error 193.6
Rainfall	P_W = Annual Precipitation at site H32072 Whytes P_S = Annual Precipitation at site H32061-71 Sandhurst P_T = Combined Annual Precipitation at sites H22941 Melrose, H22961 Glenallen, H32061-71 Sandhurst and, H32072 Whytes	$F_{Waipara} = 1.435 \times P_W - 8.970 \times P_S + 4.268 \times P_T - 4196.957$	0.966	220.0 Standard Deviation of error 187.6

The flow model tended to underestimate high flows and overestimating low flows, while the errors in the rainfall model were more variable as shown in Figure 4-13. To improve the accuracy of the model, the flow estimates from each model were weighted according to the standard deviation of their respective errors and then combined. By using the combined model, the standard deviation of the error reduced to 119 l/s.

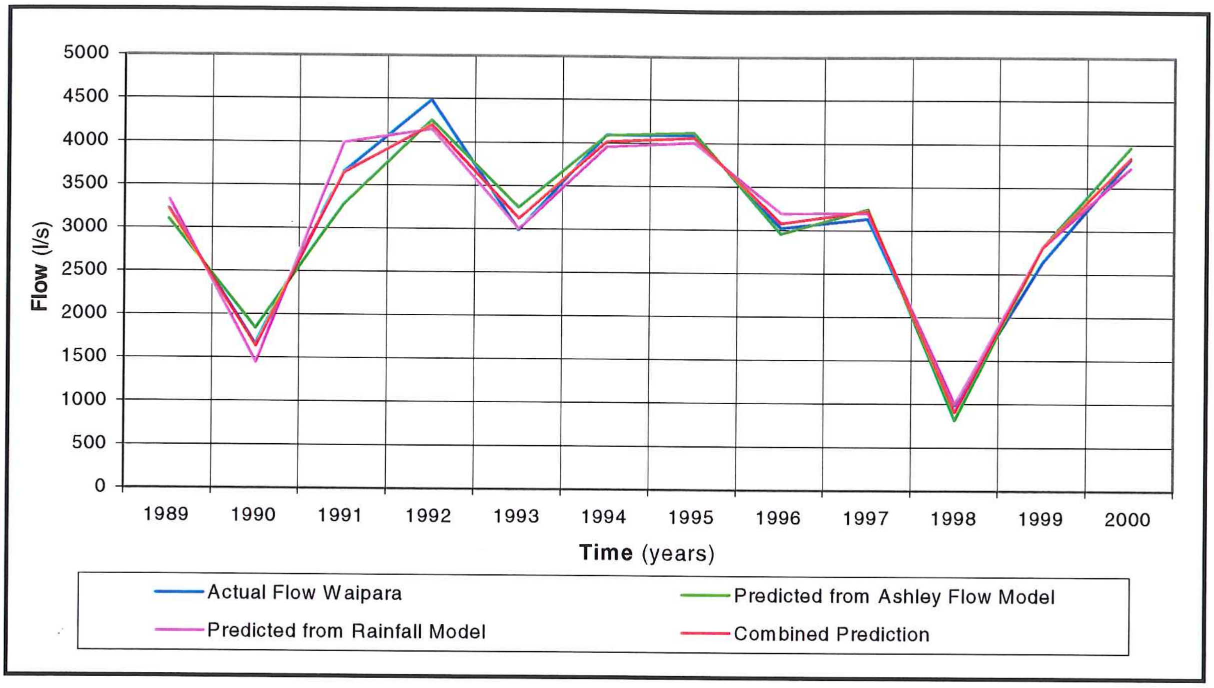


Figure 4-13 ***Plot of Predicted and Actual Flows in the Waipara River from 1988 to 2000.***

Using the models (the combined model for the period 1973-1988, and the rainfall model for 1951-1972), the mean annual flow record of the Waipara River at White Gorge was extended back to 1951 as shown in Figure 4-14. The mean annual 1951-2000 flow in the Waipara River at White Gorge was 3308 l/s, which is 160 l/s higher than the mean annual 1989-2000 flow of 3148 l/s, indicating that the 1989-2000 period was dryer than the longer term average.

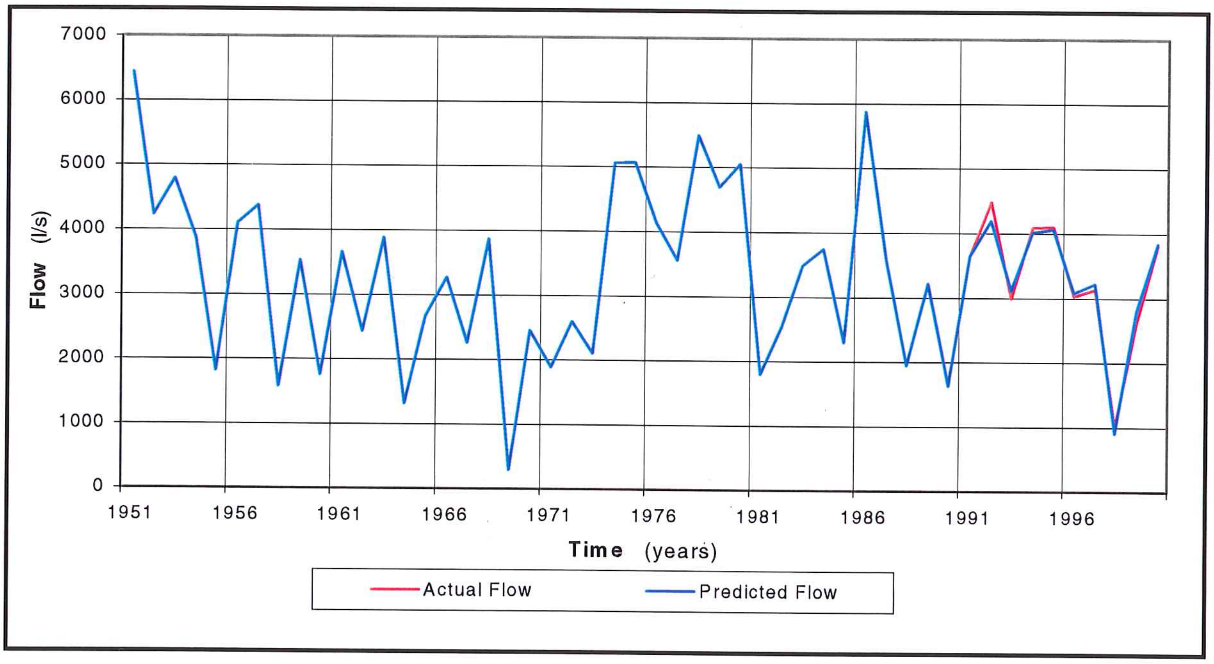


Figure 4-14 ***Plot of the Predicted mean annual flow in the Waipara River at White Gorge from 1951-2000***

Given the limited length of flow records and to account for significant seasonal variations in both evapo-transpiration and river flows, the models were reworked using both seasonal (summer December-February, autumn March-May, winter June-August and spring September-November) and monthly data. On a seasonal basis mean flow at White Gorge correlated quite well with mean flow in the Ashley (R^2=0.854); however monthly flows did not correlate well (R^2=0.771). The best three variable models for seasonal and monthly data had correlation factors of R^2=0.905 and R^2=0.811 respectively. This suggests that for shorter timeframes localised weather patterns, soil moisture conditions and lag times between rainfall and runoff become significant.

4.4 SPRINGS

Springs are points where groundwater discharges to the surface due to topography (depression springs), and/or geological features (contact and sinkhole springs), and/or structural constraints (fault, joint and fracture springs) (Fetter, 1994). Springs represent a significant water resource which provide domestic and stock water.

4.4.1 INTRODUCTION

On 1 June 2001 Environment Canterbury's springs database contained 21 springs within the Waipara catchment. During landowner interviews undertaken by the author, a further 186 springs were identified. The springs were identified by the permanence of their discharge and whether or not they were tapped. Figure 4-15 summarises these data and shows the location of the springs in the catchment (map references and details of the springs are included in Appendix 4.5).

The majority of the springs in the area are classified as contact springs and occur where a permeable rock unit overlies units of much lower permeability (Fetter, 1994). Many of the high yielding springs are related to differing beds within the tertiary (limestone, sandstone and mudstone) rock units of the area. Two lines of springs flank the Omihi Valley along the Mount Cass and Mount Donald Ranges. These springs generally align themselves with the lithologic contact between overlying limestone/sandstone beds and underlying mudstone beds. Many springs discharge directly from the base of limestone outcrops.

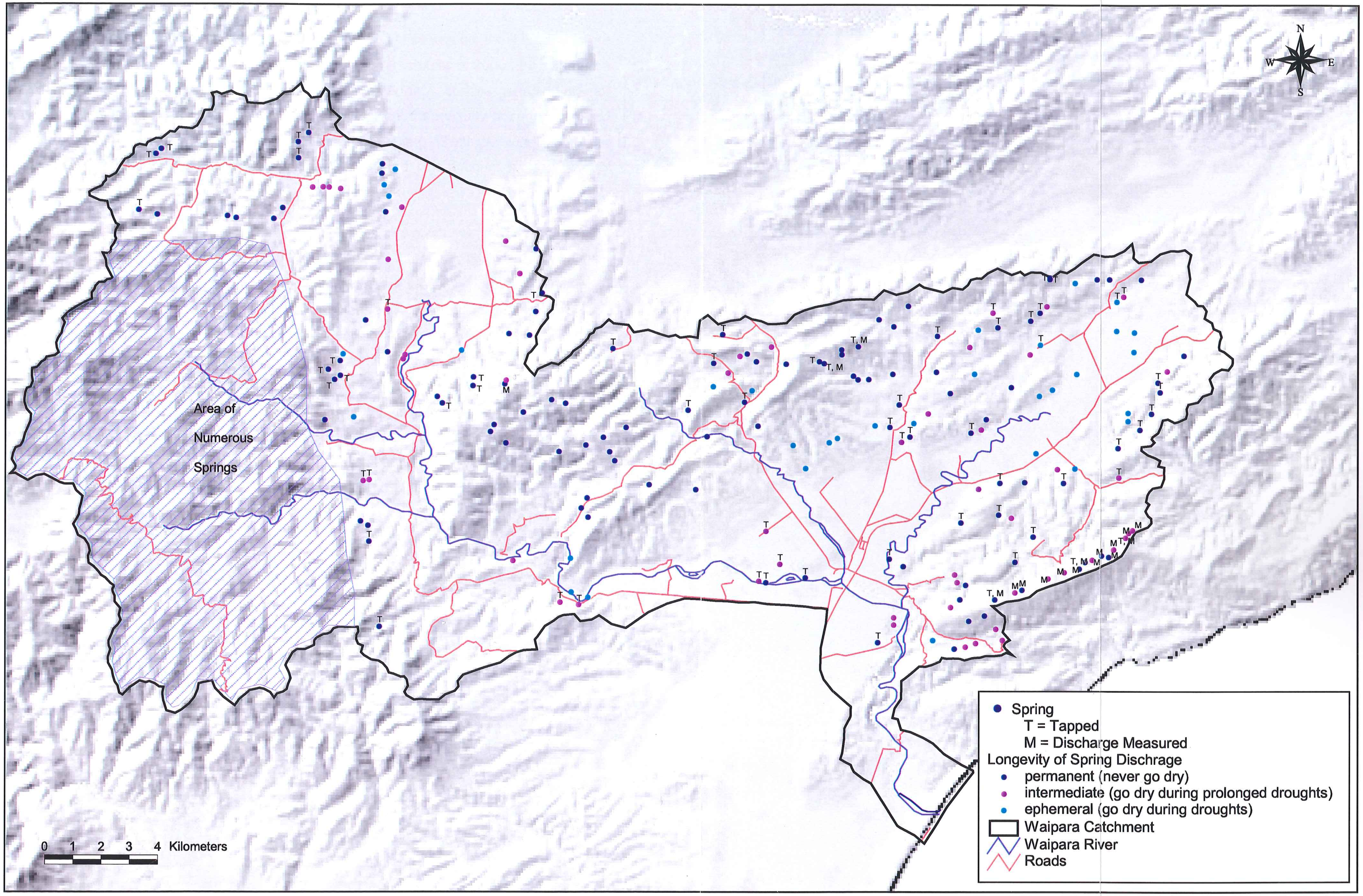


Figure 4-15 Springs within the Waipara Catchment

4.4.2 CASE STUDY - SPRING FLOW

Flow from many of the area's springs remains fairly constant throughout the year and is not significantly affected by drought conditions. During the dry summer of 2000-2001 when the area's creeks and rivers were either dry or had very limited flow, springs generally did not experience a significant drop in flow. Science indicates that the majority of springs are fed from precipitation which infiltrates up-slope from the spring (Pettinga, 2001). Water percolation through the rock mass is often very slow and can account for the lack of variability of spring flow.

A number of springs are situated very close to ridge tops and given the limited rainfall in the Waipara area doubts have been raised over the source of the spring discharge. A number of landowners on the flanks of the Omihi Valley suspect the flow from their springs is affected by groundwater abstractions in the valley floor and have lodged their concern with Environment Canterbury. The effects of gravity and the change in lithology between the gravels of the Omihi Valley and the tertiary sediments from which the springs emerge, suggest that the groundwater within each unit is not significantly connected. To further assess this, water balances were conducted on the catchments of 16 springs in the area (13 along the Mount Cass Range, two from Mount Donald and one to the west of the Doctors Hills). The discharge from each of the springs was measured in July 2001 to determine maximum spring discharge (Table 4-9).

Table 4-9 Discharge Rates from various springs in the Waipara Catchment

Spring Number	Location (property name)	Elevation	Catchment Area	Discharge	
		m	ha	l/minute	mm/year
1	Mount Cass	457	12.0	4.0	18
2	Hamilton Glens	395	9.1	1.4	8
130	Hamilton Glens	353	3.2	2.0	33
131	Hamilton Glens	334	4.0	1.5	20
132	Hamilton Glens	376	9.3	1.4	25
133	Hamilton Glens	418	8.9	3.0	18
134	Hamilton Glens	416	8.7	2.7	16
135	Hamilton Glens	428	15.7	2.4	8
136	Hamilton Glens	452	13.1	2.5	10
137	Hamilton Glens	441	11.9	1.0	4
138	Hamilton Glens	457	11.0	2.0	10
139	Hamilton Glens	399	19.7	5.6	15
140	Hamilton Glens	374	13.4	2.0	8
N34/152	Hamilton Glens	462	13.6	6.3	24
50	Mount Donald	375	20.6	16.5	42
48	Shellrock	305	10.7	7.8	38
82	McKnights	518	13.7	19.8	76

The topographic catchment of each spring was determined from aerial photos and the average annual precipitation on the catchment was estimated from the rainfall map produced in Chapter 3 (Figure 3.3). Average annual actual evapo-transpiration rates were taken from the soil water balances (Table 3.5, Chapter 3) undertaken at Hamilton Glens (for the Mount Cass springs), Manahune (for the Mount MacDonald springs) and at Glenallen (for the spring on the Doctors Hills). A simple water balance was undertake for the topographic catchment of each of the springs which revealed that in excess of 33% of annual precipitation is available for infiltration and storm water runoff (Table 4-10).

Table 4-10 Water Balance for the Catchment of various springs in the Waipara Catchment

Spring Number	**Annual Precipitation**	**Actual Evapo-transpiration**	**Spring Discharge** (Groundwater discharge)	**Water Balance** (water available for storm runoff and infiltration to groundwater)	
	mm/year	mm/year	mm/year	mm/year	% of precipitation
1	1150	536	18	596	52
2	1150	536	8	606	53
130	1100	536	33	581	50
131	1100	536	20	594	52
132	1100	536	25	589	51
133	1150	536	18	596	52
134	1150	536	16	598	52
135	1150	536	8	606	53
136	1150	536	10	604	53
137	1150	536	4	610	53
138	1150	536	10	604	53
139	1150	536	15	599	52
140	1150	536	8	606	53
N34/152	1150	536	24	590	51
50	800	495	42	263	33
48	800	495	38	267	33
82	900	459	76	365	41

The water balances indicate that the amount of water available for surface runoff and infiltration is between 5 and 150 times greater than the volume of water the springs discharge. It is concluded that the springs on the flanks of the Omihi Valley are fed by precipitation which infiltrates into the catchment area upslope of the spring outlet. This fact coupled with the change in lithology, indicates that groundwater abstractions from the gravels of the Omihi Valley are very unlikely to affect the discharge from the springs which emerge from the tertiary sediments on the flanks of the valley.

4.4.3 EXISTING USE

Springs provide a significant water resource in the catchment. Of the 207 springs identified, 67 are tapped and provide water for domestic, stock water and in four cases irrigation supply, while the 140 untapped springs provide an important source of stock water, for the area. A survey of 106 landowners throughout the catchment revealed that spring and river water makes up 61% of the areas stock water requirements, groundwater makes up 4% and the remaining 35% comes from the various rural water supply schemes. Of the 211 houses covered by the landowner survey, 58 (28%) obtain their domestic water from natural springs and rivers, 26 (12%) from groundwater wells and the remaining 127 (60%) from the rural water supply schemes.

On 1 June 2001 the Environment Canterbury consents database contained two current consents relating to the use of spring water. Under the current Council Bylaws the abstraction of small quantities (up to 10 cubic meters per property per day) of surface water is considered a permitted activity. The tapping and use of springs generally falls within this limit which explains the lack of consents.

4.5 SURFACE WATER STORAGE

Surface water storage within a catchment occurs due to four main reasons: snow cover, swamps and wetlands, natural lakes and constructed dams and reservoirs. Within the Waipara Catchment, natural water storage is minimal which is reflected in the very variable nature of flows in the Waipara River.

While snow falls are common in the upper catchment over the winter months, it usually melts within a few days and a snow cover is not established for any length of time. As such, the storage of water within snow is insignificant in the Waipara Catchment. There are few swamps in the catchment and the few that exist in the upper catchment are all relatively small (less than 1 ha) and do not store a significant volume of water.

Two natural lakes exist within the Waipara Catchment (Lake Raupo on Home Creek, and an unnamed lake west of The Deans range of hills), both of which were created by landslides blocking drainage paths. Both lakes are fairly small and do not represent a significant volume of water storage. There are 16 water harvesting storage dams within the catchment, 11 of which are related to the Glenmark Irrigation Scheme. Based on the design details for the dams, it is estimated that a total of approximately 1.2 million m^3 of water is stored for irrigation purposes. It is normal practice that the dams are filled once a year during winter and then drained for irrigation over summer which means that for the Waipara catchment storage for irrigation represents 0.002 mm/yr (which is insignificant compared to the average annual precipitation of 771 mm/yr). Over 400 small stock dams scattered throughout the catchment were identified during landowner interviews. Many of these stock dams dry during the summer and while they provide a significant source of stock water they do not represent a significant amount of water storage. Environment Canterbury's resource consent database contains 11 current consents to dam water and 3 to divert water within the catchment (Table 4-5).

The irrigation storage dams are operated under standard water harvesting principles whereby the dams are filled during the wetter winter months and then are substantially drained for irrigation purposes over the summer months. Of the 16 water storage dams in the catchment, 5 were not fully utilised during the 2000-2001 summer due to a combination of incomplete onfarm infrastructure and farm management decisions. The Glenmark scheme was initially designed for the irrigation of 36 ha of essentially grain and feed crops per farm. Changes in farming practices over the last decade have caused a shift from the irrigation of crops to the establishment of irrigated vineyards on a number of properties. This has led to a reduced water usage due to the generally smaller size of the vineyards, more water efficient irrigation practices and most importantly the reduced water demand per hectare of grapes as opposed to crops.

In the design of the Glenmark Irrigation Scheme, Heiler (1977) calculated that evaporation and leakage losses would account for a maximum of 23% of the volume of the storage dams with the remaining 77% available for irrigation. It is assumed that a similar division would be applicable to the other storage dams in the area.

4.6 SUMMARY

The surface water resources of the Waipara catchment are extremely seasonal. Runoff is very limited during summer (due to high evapo-transpiration rates) resulting in low flows in the area's watercourses. The low flows coincide with the period when demand for irrigation water is at it highest. Investigations are undertaken to determine the extent of the surface water resources, their current use and to assess their ability to sustain further development. The key findings of these investigations are:

River Flow:

- Two continuous flow recorders are situated along the Waipara River: at White Gorge in the upper gorge and Teviotdale in the lower gorge.
- Records from White Gorge reveal that the 1989-2000 mean annual flow was 3148 l/s. Utilising a runoff model the 1951-2000 mean annual flow was calculated at 3308 l/s which suggests that the 1989-2000 was slightly drier than the long term average.
- The flow pattern is strongly seasonal with mean monthly flows varying from 520 l/s during January to 7285 l/s during July.
- Flow in the Waipara River is dominated by long periods of low flow and large infrequent short duration flood events. At White Gorge mean daily flows of less than 88 l/s are

recorded on average 11 times a year while flows of greater than 20 m^3/s are recorded on average 7 times a year.

- The Waipara River gains flow (predominately from tributary inflow) over all its length, and is not significantly connected to groundwater other than below the Teviotdale Bridge (where the river often runs dry) and in small sections of the upper catchment.
- Flow in Weka Creek, Home Creek and Omihi Stream is strongly connected to groundwater with significant gains and losses to and from groundwater.
- During periods of low flow, Omihi Stream contributes approximately 50% of the flow that passes the Teviotdale recorder site. During periods of high flow, runoff from the upper catchment becomes dominant.
- Catchment runoff is very low being only 6.4 $l/s/km^2$, highlighting the dry nature of the Waipara catchment when compared to adjacent catchments (the Ashley to the south 10.8 $l/s/km^2$ and the Hurunui to the north 20.3 $l/s/km^2$).
- The surface water resources of the Waipara Catchment are highly utilised with a total of 1491 l/s currently allocated via 29 resource consents. A further 23 properties abstract surface water under Environment Canterbury's General Authorisations.

Springs:

- A large number of springs exist within the Waipara catchment which provide a significant source of stock and domestic water.
- A significant number of springs are found within the tertiary rock units of the area and are fed by precipitation which infiltrates into the catchment area upslope of the spring outlet.

Water Storage:

- Natural water storage within the catchment is very limited.
- Approximately 1.2 million m^3 of water is stored in various dams and reservoirs throughout the catchment, the majority of which are associated with the harvesting of winter flood flows for summer irrigation purposes.

In order to further understand Waipara's water resources, the characteristics of the surface water resources will be used to develop a water balance for the catchment in the following chapter. The surface water resources of the Waipara catchment are already very highly allocated and potential abstraction rates far exceed normal summer supply. This situation resulted in a hearing of the Environment Court and causes a significant challenge to water managers. This issue is discussed further in Chapter 7 which considers water management.

5 GROUNDWATER RESOURCES AND USE

5.1 INTRODUCTION

This chapter describes both the occurrence of groundwater within the Waipara catchment and its existing use. It builds on a recent study by Loris (2000) and aims to provide enough information to allow groundwater management options to be discussed in later chapters. The chapter is separated into three sections covering:

- a brief hydrogeological description of the aquifers,
- a summary of the existing wells and boreholes in the area including existing groundwater use, and
- groundwater recharge.

The chapter commences with a brief discussion of previous work and then describes the findings of this research. Existing use of groundwater is included as it is necessary to consider both the extent of the resource and existing usage when developing future management options.

Throughout this document the term 'well' is taken to mean a shallow, hand-dug, usually bricklined hole used to extract groundwater, whereas a 'borehole' is considered to be a mechanically drilled hole which has a steel or PVC casing.

5.2 HYDROGEOLOGY AND DESCRIPTION OF THE AQUIFERS

5.2.1 PREVIOUS WORK

The first published investigations of the hydrogeology of the Waipara Catchment were undertaken in 1972 when the potential of wells in the Glenmark-Waipara area to provide irrigation water was assessed (Borrie et al., 1972). The study found that the existing wells could not provide a viable source of irrigation water. This conclusion was supported by a similar study by Wilson in 1983 as part of the development of the Glenmark Irrigation Scheme. Wilson's study concluded that:

> *'In view of the nature of the sequence* (of strata) *beneath Glenmark I am pessimistic about the prospects of finding aquifers capable of yielding as much as 10l/s, let alone capable of yielding true irrigation yields exceeding 30l/s.' (Wilson, 1983, p22)*

Since 1990, Environment Canterbury has maintained various databases on Canterbury's groundwater system. On 1 November 2001 the databases contained records from 276 wells and boreholes in the Waipara Area.

Loris' *Hydrogeology of the Waipara Alluvial Basin* (2000) represents the most complete and up-to-date summary of the hydrogeology of the lower Waipara catchment. Loris' work along with seismic surveys currently being undertaken in the Omihi Valley (Finnemore and Pettinga, in press) represent the current state of knowledge in relation to the hydrogeology of the area.

5.2.2 The Water Bearing Units

As outlined in Chapter 2, the geology of the Waipara Catchment consists of Torlesse Supergroup (Greywacke and Argillite) basement rocks overlain by a Tertiary marine transgression-regression sequence of sandstone, mudstone and limestone rock units. Extensive fluvial and glacial gravels have infilled the two main synclinal basins (Waipara syncline and MacDonald syncline) within the catchment.

The Torlesse basement rock has limited porosity and although highly fractured, does not store or transmit significant quantities of water and is not considered a potential groundwater source.

The Tertiary marine deposits of the catchment have the potential to contain aquifer systems especially within the limestone units where solution mechanisms can result in underground rivers (e.g. Cave Stream, North Canterbury). The depth of the units throughout much of the catchment, the lack of detailed studies and the presence of aquifers in the overlying gravel deposits has discouraged drilling into the Tertiary units. Of the 276 wells and boreholes in the Waipara Area on Environment Canterbury's database, only 1 (M34/5573) is drilled into the Tertiary deposits. In addition, the author is aware of one further dry borehole that was drilled to a depth of 90 m into Tertiary mudstones and sandstones in the Upper Waipara River Valley. Borehole M34/5573 is situated where the Waipara River flows out of White Gorge and enters the Waipara Alluvial Basin. The borehole was drilled to a depth of 90.5 m and passes through various gravel and clay units (the Kowai formation) before encountering sandstone and limestone layers (the lower Kowai Greta beds and the Mount Brown Formation). The borehole draws artesian water from gravels encountered below the limestone sandstone units. The presence of gravels below the limestone sandstone units is unusual, as the Mount Brown Formation is not known to contain gravel beds and could indicate that the borehole has crossed the Boby Creek fault (known to exist in the vicinity). The borehole has a yield of 25 l/s, which is high for the Waipara area and has encouraged further drilling into the Tertiary rock units (three boreholes are currently proposed).

Historically, the search for groundwater in Waipara has focused on the gravel deposits which infill the Waipara Alluvial Basin and the Upper Waipara River Valley. These gravels are separated into the older Kowai Formation and the overlying Quaternary deposits of the Teviotdale, Canterbury and Recent Gravels. The lack of boreholes in the Upper Waipara River Valley prevents the aquifers of the upper catchment being accurately described and the following comments are based on analysis of the boreholes in the Waipara Alluvial Basin. However, as the same gravel units are present in the Upper Waipara River Valley, it is expected that the aquifers will be similar.

(a) Kowai Formation

The Kowai Formation consists of two units; early Pliocene marine conglomerate and siltstone deposits, and a thick overlying sequence of early Pleistocene fluvial gravels (Kowai Gravels). The original thickness of the Kowai Formation is estimated at between 580 and 650 m (Browne and Field, 1985). The Kowai Gravels consist predominantly of weathered greywacke and agrillite clasts with some sparse tertiary derived clasts in a silty clay matrix. The clasts are rounded to subangular and are poorly sorted (Wilson, 1963; Wilson, 1983).

A 200 m deep borehole (N34/0296) recently drilled near Omihi School in the middle of the Omihi valley to calibrate a seismic survey undertaken by Finnemore and Pettinga (in press), penetrated the Kowai Gravels at a depth of approximately 160m. The Kowai Gravels were found to be very well compacted clay and silt bound gravels that were difficult to drill through. The high clay content and compacted nature of the Kowai Gravels suggest that the gravels will have very low permeability. The presence of numerous streams in the area that have surface flow over the Kowai Gravels but then disappear (flow underground) when they encounter the Teviotdale and Canterbury Gravels support this suggestion. In their ongoing work identifying sources of groundwater in the Omihi Valley, Finnemore and Pettinga are concentrating their efforts on the Teviotdale and Canterbury Gravels as they do not believe the Kowai Gravels will contain any economic aquifers (Pettinga, 2001).

(b) Quaternary Gravels

The Quaternary Gravels are separated into the older Teviotdale and Canterbury Gravels and the younger Recent Gravels.

(i) Teviotdale and Canterbury Gravels

The Teviotdale and Canterbury Gravels represent the two main aggradation deposits of the last glaciation separated by a period of river downcutting (Wilson, 1963). The Teviotdale

Gravels consist of creamy brown, leached clasts within a supporting matrix of yellow-brown fine sand and silt. The clasts are predominantly greywacke and argillite with a few scarce Tertiary clasts (Wilson, 1963). Tilting of the beds indicates that deformation occurred either during deposition or soon after (Yousif, 1987; Nicol et al., 1994). The Canterbury Gravels represent a younger version of the Teviotdale Gravels, are grey to brown-grey in colour with a lower proportion of silty and sandy matrix. The gravels are clast supported and consist of predominantly greywacke clasts (Wilson, 1963).

Most of the wells and boreholes in the area, tap aquifers situated within the Teviotdale and/or Canterbury Gravels. The aquifers represent buried river channels within the gravel units and are described by Loris (2000) as a complex network of discrete, lithologically and hydraulically heterogeneous and anisotropic semi-permeable to permeable channels. The aquifers occurring within both the Teviotdale and Canterbury gravels have similar lithologies, yields and thickness and are difficult to distinguish from one another and for the rest of this study are defined as the Canterbury/Teviotdale Aquifer system. Varying depositional history and associated tectonic activity complicates the lateral extent of the formations and the associated aquifers (Loris, 2000). Aquifer tests undertaken by Loris indicate that the deeper aquifers are slightly more transmissive although the deeper boreholes tend to have longer screens that extend over a number of water bearing units. The aquifers are generally confined to semi-confined with a number of boreholes yielding flowing artesian water.

(ii) Recent Gravels

Recent Gravels are fluvial gravels which form thin veneers on the degradation terraces and current flood plains of the Waipara River and its tributaries (Loris, 2000). The deposits consist of large boulders and gravels, which are clast supported within a silty clay matrix. The boulders and gravels vary from predominantly greywacke in the Waipara River to predominantly Tertiary in Omihi Stream and Home Creek. Abstraction galleries and shallow wells situated within the current flood plains indicate that the recent gravels have a high hydraulic conductivity and are hydraulically connected to the adjacent surface water features.

5.2.3 CONCEPTUAL MODEL OF THE AQUIFER SYSTEM.

A conceptual model for the aquifers of the Waipara Area is presented in Figure 5-1. The known aquifer system is made up of a series of buried meandering river channels within the Canterbury and Teviotdale Gravels (Loris, 2000). Borehole M34/5573 suggests further aquifers within the lower Kowai Formation (Greta Beds) or the Tertiary Formation (Mount Brown Beds). This is supported by the presence of numerous sinkholes and springs within the Tertiary beds and the identification of surface water losses to groundwater where rivers and creeks cross the Tertiary beds. If aquifers are present in the Lower Kowai or Tertiary Formations they are likely to be confined to individual beds. The presence of numerous siltstone and other impermeable beds within the Lower Kowai and Tertiary Formations and the low permeability of the Kowai Gravels would tend to prevent interaction between the two aquifer systems.

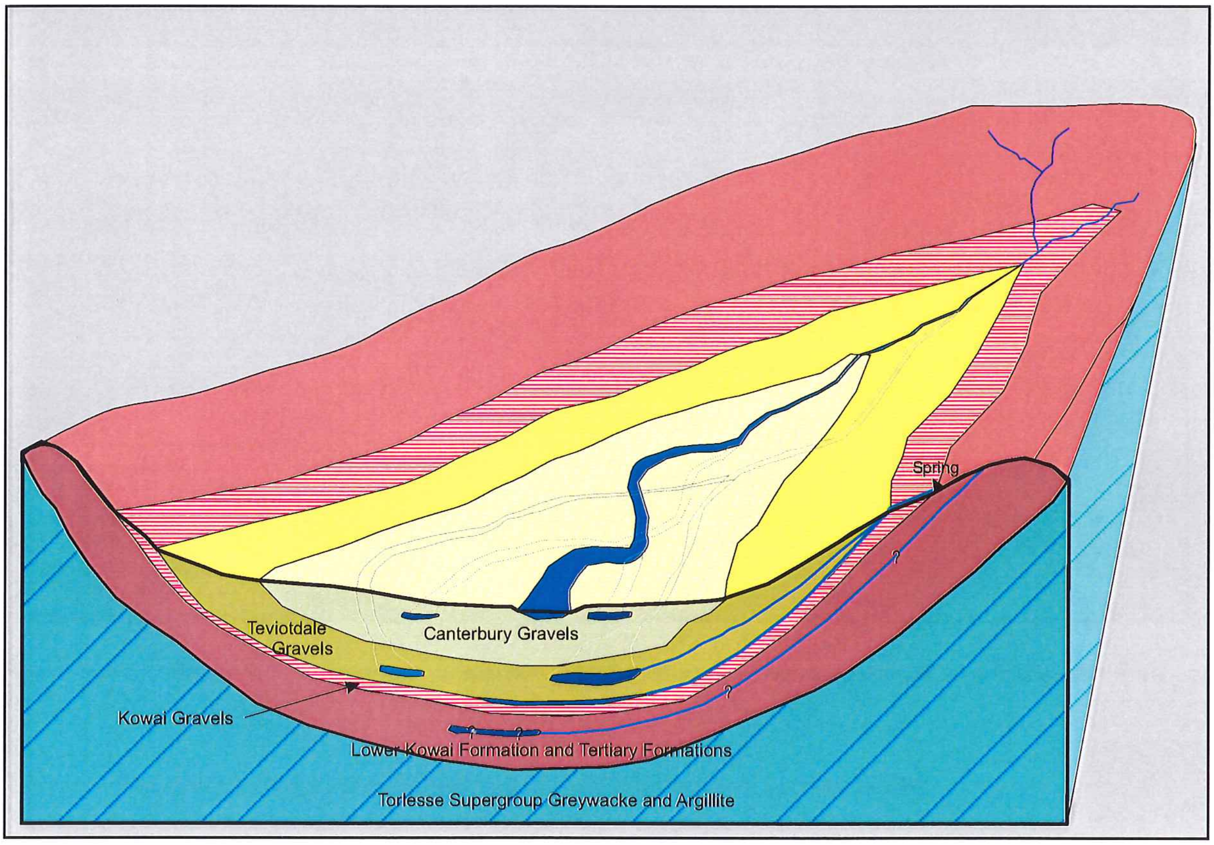


Figure 5-1 Conceptual Model of the aquifer systems in the Waipara Catchment (modified from Loris 2000)

5.3 EXISTING SITUATION

5.3.1 EXISTING WELLS AND BOREHOLES

On the 1 November 2001 there were 178 existing and 27 proposed wells and boreholes recorded on Environment Canterbury's Wells Database for the Waipara catchment, with a further 98 existing and 2 proposed wells recorded for the Glasnevin Flats area. In addition the author is aware of one further borehole which was drilled in the Upper Waipara River Valley. As shown in Figure 5-2, the majority (247 out of 277) of the wells and boreholes are situated within the Waipara Alluvial Basin and on the Glasnevin Flats.

The wells vary from shallow hand dug brick lined wells constructed in the early 1900's through to modern steel cased boreholes extending down to 200m below the surface. The wells and boreholes are almost exclusively situated in the Quaternary gravels and draw water from small buried river channels (the Canterbury/Teviotdale Aquifer system).

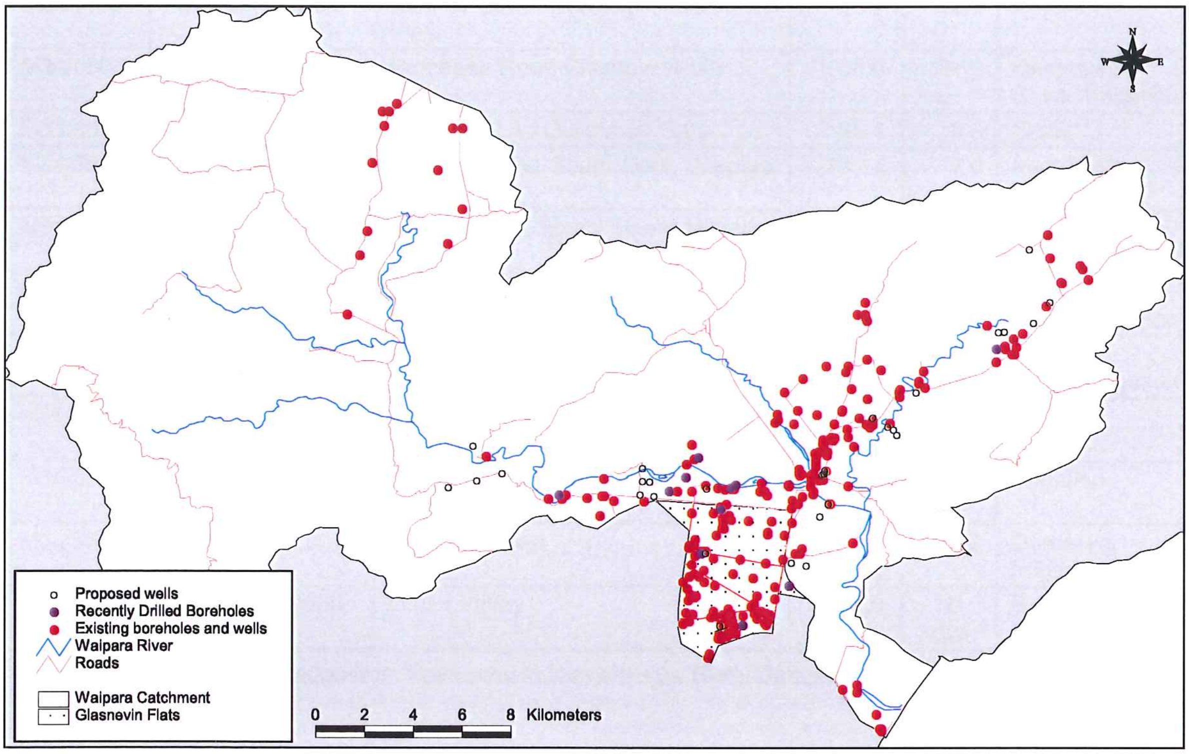


Figure 5-2 Existing and Proposed Wells and Boreholes in the Waipara Area as at 1 November 2001

(a) Recently Drilled Boreholes in the Waipara Alluvial Basin

Since Loris' study eleven boreholes have been drilled within the study area (Table 5-1). Most of the new boreholes have been drilled in the search for irrigation water and have targeted the deeper higher yielding aquifers with eight of the eleven being drilled to over 80m. Four of the new boreholes (M34/0772, M34/0805, M34/5573, M34/5574) have found water a yield greater than 17 l/s. This has increased interest in groundwater and currently there are a further 29 boreholes proposed to be drilled in the Waipara area. A copy of the borelogs for the 11 new boreholes is included in Appendix 5.1.

Table 5-1 Boreholes recently drilled in the Waipara Area.

Bore Number	Grid Reference	Position	Depth m	Yield l/s	Use
M34/0772	M34:8901-8893	East of State Highway 1 Glasnevin Flats	89.7	32.6	Irrigation
M34/0805	M34:85384-90258	Purchase Road Glasnevin Flats	36.0	21.0	Domestic, Stock, Irrigation
M34/5519	M34:8712-8733	Stanton Road Glasnevin Flats	35.4	0.8	Stock
M34/5537	M34:8410-9280	Upper terrace South Bank Waipara River	191.1	7.5	Irrigation
M34/5540	M34:8499-9273	Mid terrace South Bank Waipara River	160.0	Nil dry	Irrigation
M34/5570	M34:8681-9305	Lower terrace south bank Waipara River	86.0	3.3	Domestic, Stock, Irrigation
M34/5573	M34:7957-9264	North bank Waipara where it flows into the Basin below White Gorge	90.7	25.0	Domestic, Stock, Irrigation
M34/5574	M34:8528-9417	Upper Terrace north bank Waipara River	114.2	17.8	Irrigation
M34/5585	M34:8662-9293	Lower River Terrace south bank of Waipara River	83.0	3.5	Irrigation
M34/5586	M34:8620-9207	Georges Road	58.8	2.0	Domestic, Irrigation
N34/0296	N34:9750-9859	Omihi Valley	200.0	Nil dry	Seismic Investigation

Information from Environment Canterbury's Wells Database and interviews with landowners.

5.3.2 WATER YIELD FROM WELLS AND BOREHOLES

Water yield from the wells and boreholes in the area varies significantly from less than 0.25 l/s through to 32 l/s. Yields are generally low with yields greater then 10 l/s the exception rather than the rule. Water yield is poorly correlated to location highlighting the complicated depositional history of the area discussed by Loris (2000). High yielding shallow boreholes are often situated within a few hundred metres of deeper boreholes which are dry or poorly yielding (Figure 5-3).

Yield generally increases with depth (Figure 5-4), although it is noted that boreholes M34/5540 and N34/0296 were recently drilled to a depth of over 150 m and were essentially dry. All the wells and boreholes that draw water from above the surrounding watercourses have yields less than 3 l/s. Yields of greater than 10 l/s only occur in wells and boreholes which are either directly connected to surface water flows, or are greater than 50 m in depth and draw water from below the level of the area's watercourses (Figure 5-4). This suggests that seepage from watercourses may be a significant source of recharge and that perched water-tables are common.

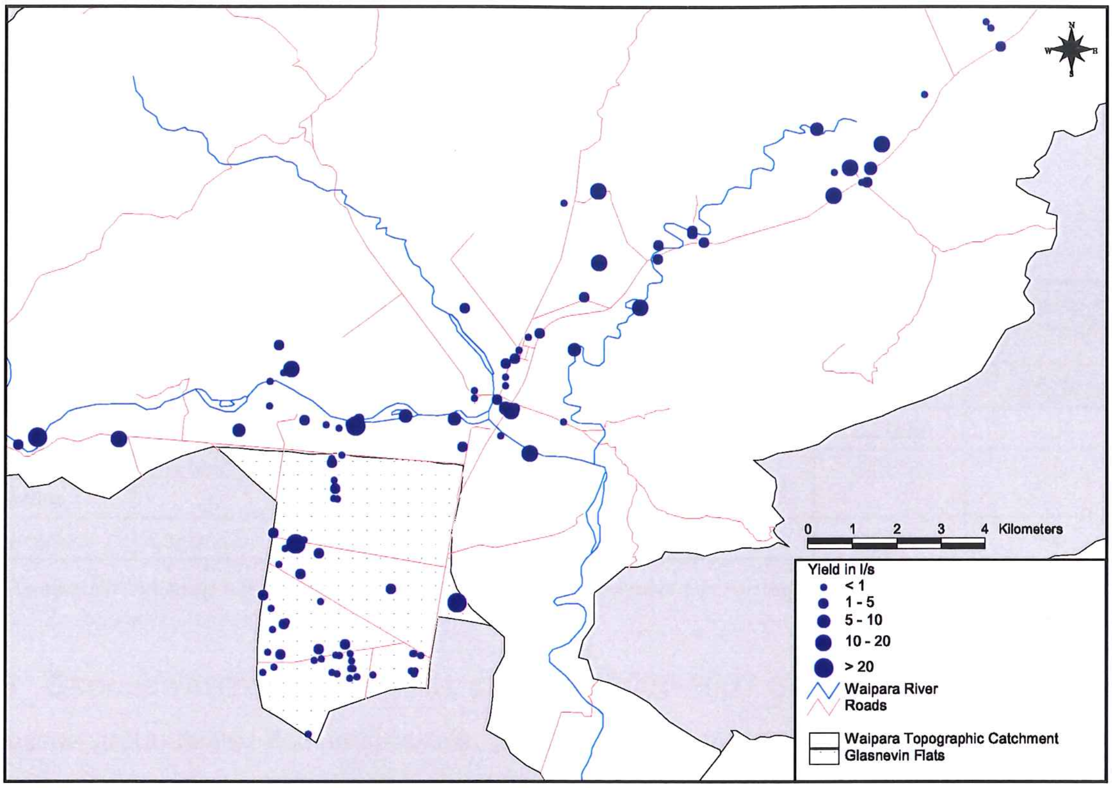


Figure 5-3 ***Boreholes and Wells with known yield in the Waipara Alluvial Basin.***
(Adapted and updated from Loris 2000)

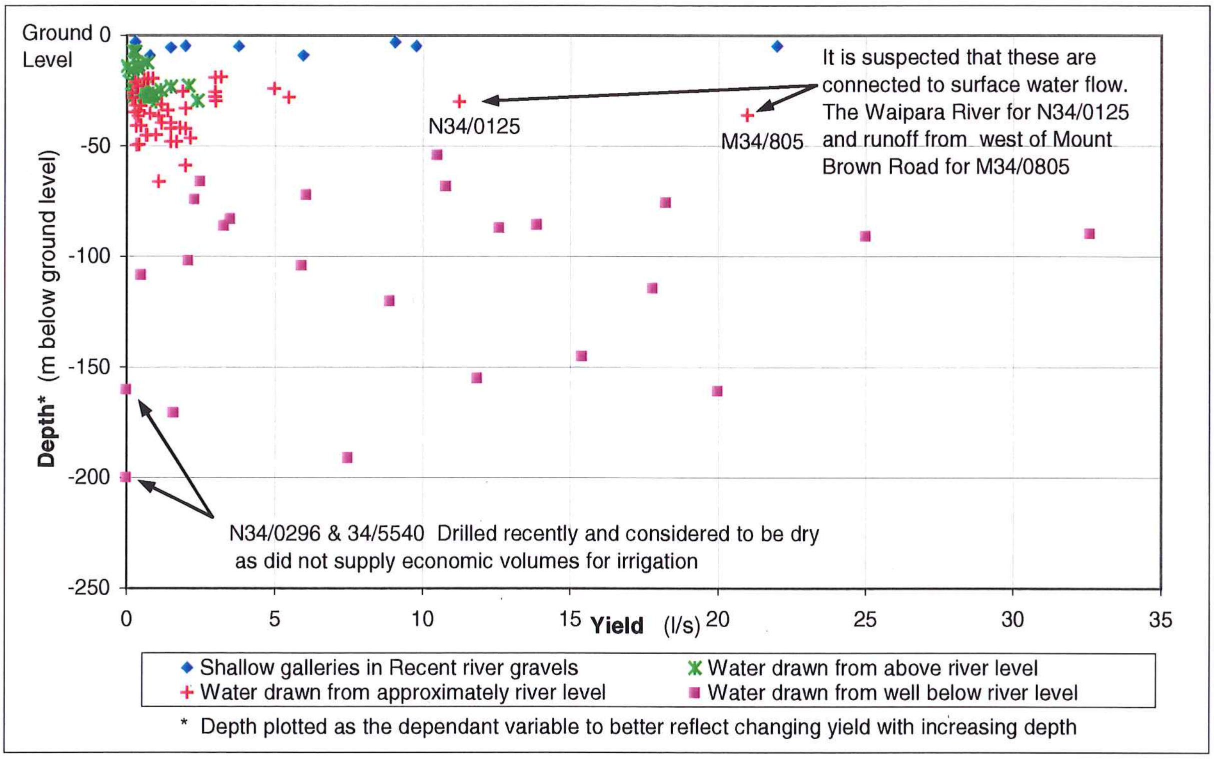


Figure 5-4 Water Yield as a Function of Depth for Wells and Boreholes in the Waipara Alluvial Basin
(Adapted and updated from Loris 2000)

The Waipara aquifers are of limited thickness, are not laterally extensive, do not transmit water very fast and when pumped experience large drawdowns. Aquifer tests undertaken by

Loris (2000) indicate that the Waipara aquifers have extremely low transmissivity, storativity and hydraulic conductivity (Table 5-2). The aquifers have the potential to supply water for relatively small scale irrigation but are unlikely to yield sufficient quantities for large scale irrigation schemes.

Table 5-2 Aquifer Properties of Aquifers in the Waipara Area (from Loris 2000).

Aquifer Test Location	Aquifer	Depth of Aquifer tested (m below ground level)	Aquifer Thickness (m)	Average Transmissivity (m^2/day)	Average Storativity	Average Hydraulic Conductivity (m/day)
Georges Road	Upper CT[1]	18.6 - 27.7	4	18	0.0005	4
Broomfield – Amberley	Upper CT[1]	21.5 - 28.0	6	17	0.0001	3
Netherwood	Lower CT[1]	96.5 – 151.0	19*	92	0.0003	5

[1] The Canterbury/Teviotdale Aquifer system * The borehole is screened over two aquifers, aquifer thickness includes both.

5.3.3 GROUNDWATER FLUCTUATIONS OVER THE 2000-2001 SUMMER

To assess groundwater fluctuations over the 2000-2001 summer, the author undertook two potentiometric surveys and installed continuous water level recorders in three boreholes south of the Waipara River (Figure 5-5). As outlined previously (Chapter 4.2.8) the 2000-2001 summer was considered fairly typical in-terms-of water use.

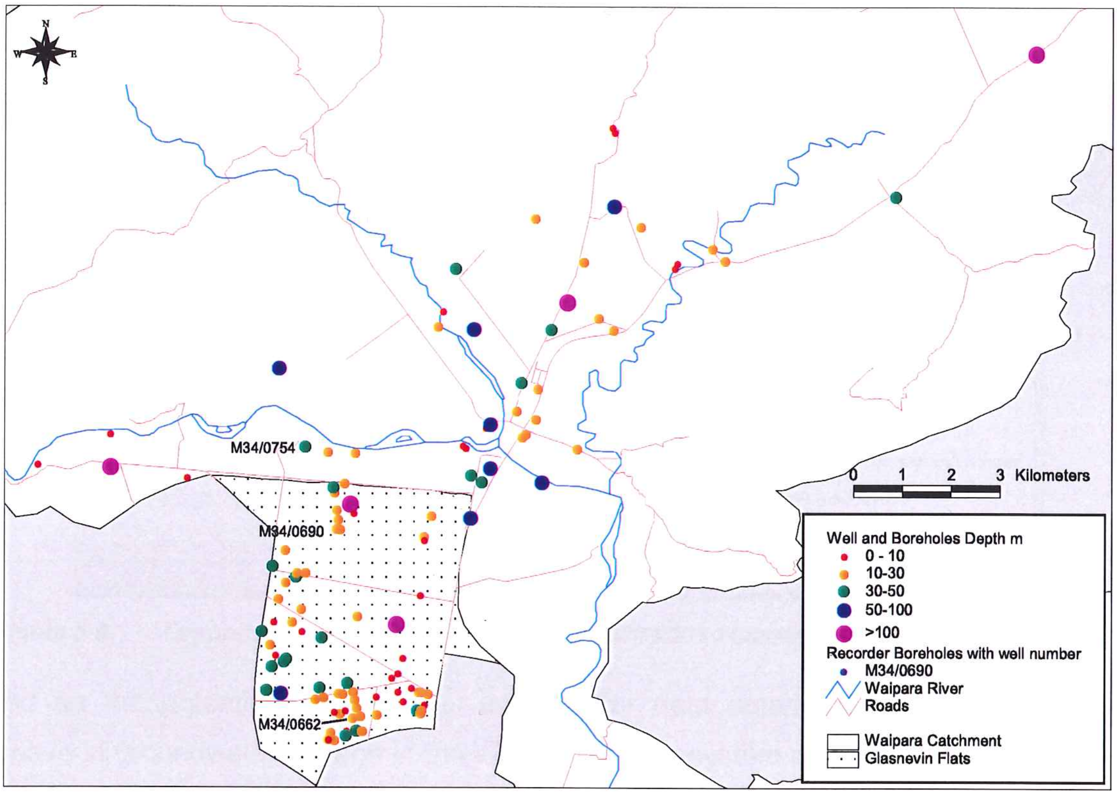


Figure 5-5 Wells and Boreholes included in the Potentiometric Surveys undertaken in the Waipara Area.

(a) POTENTIOMETRIC SURVEYS

The two surveys were undertaken in early November 2000 and late April 2001 to assess changes in groundwater levels over the summer irrigation period. Heavy precipitation and high river flows in August 2000 together with the constant precipitation that was received in September and October resulted in the Waipara groundwater system being full during the November survey. The April survey was undertaken at the end of the irrigation season prior to any significant precipitation and represents the groundwater system after a normal irrigation season. Water level readings were taken from 118 wells and boreholes throughout the Waipara area (Figure 5-5). The 118 wells and boreholes varied in depth from shallow wells less than 10 m deep to deep boreholes over 150 m deep. The water level fell in 111 cases and rose in 7. Landowner interviews revealed that the November readings in the 7 that rose were affected by pumping and the results were therefore discarded. Water levels fell by between 0.02 m to 16.84 m with an average drop of 1.54 m. Water level fluctuations were mainly related to surrounding water use, with the largest reductions occurring in the mid Omihi Valley, around the Waipara Township and within the new subdivisions off Georges Road, Racecourse Road and Mount Brown Road on the Glasnevin Flats where there is large groundwater use (Figure 5-6).

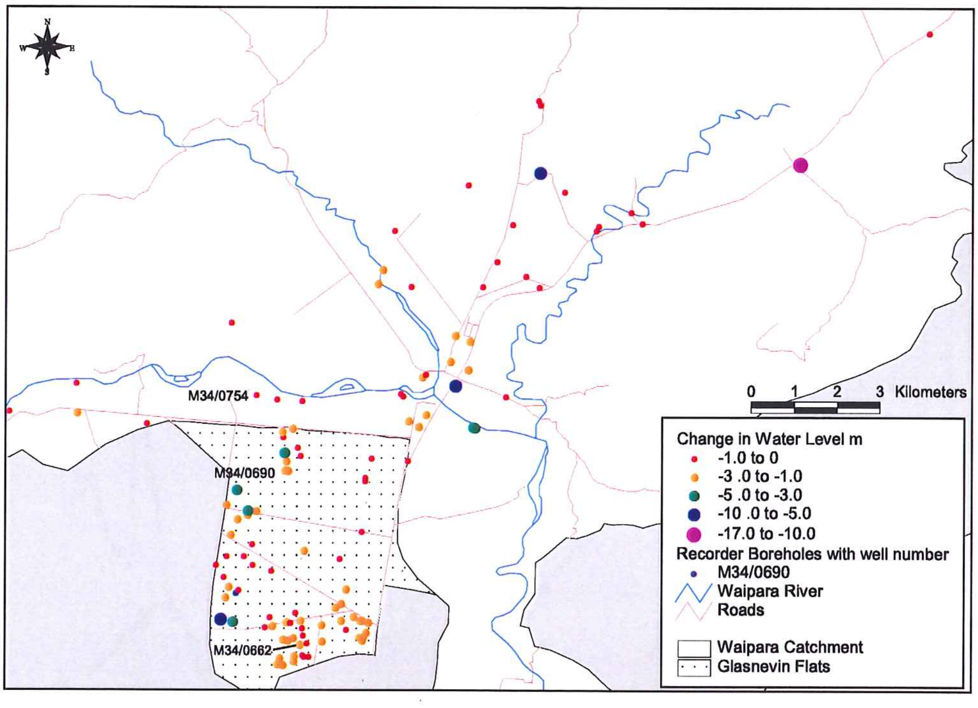


Figure 5-6 Groundwater Level changes over the 2000-2001 Summer Irrigation Season, Waipara.

Based on the potentiometric surveys and aquifer data determined by Loris (2000) the decrease in groundwater storage in the Waipara aquifer system over the 2000-2001 summer is estimated at approximately 7 million m^3 of water (error range 0.5 – 38 million m^3) (see Appendix 5.2 for calculations). Almost all (98.9%) of this change is associated with storage changes in the upper unconfined aquifer and the accuracy of the estimate is severely limited by the lack of accurate data on the storativity of the unconfined aquifer. This indicates that the volume of water stored in the confined aquifers did not vary significantly between the two potentiometric surveys.

(b) Water Level Recorders

A recorder was placed in well M34/0754 which is situated on the lower river terrace approximately 160 m south of the Waipara River (Figure 5-5) to determine if water level in the borehole fluctuated with river flow. Water level was measured using a Kainga pressure transducer connected to a Campbell 21X data logger with water level recorded every 15 minutes.

Borehole M34/0754 was drilled to a depth of 42.4 m and is screened over two sections; 31.8–33.8 m and 38.4-40.4 m (refer to Appendix 5.3 for the borehole details and the borelog). As the top of the borehole is approximately 15 m above the adjacent Waipara River the borehole draws water from below the river.

Comparison between the water level readings and flow in the Waipara River indicated a limited relationship between river flow and water level, particularly during late November 2000 when both water levels and flow in the Waipara river were declining (Figure 5-7). The lack of water level data over the 31 November-1 December 2001 flood event and the significant effects of pumping from mid January, prevent strong conclusions being made.

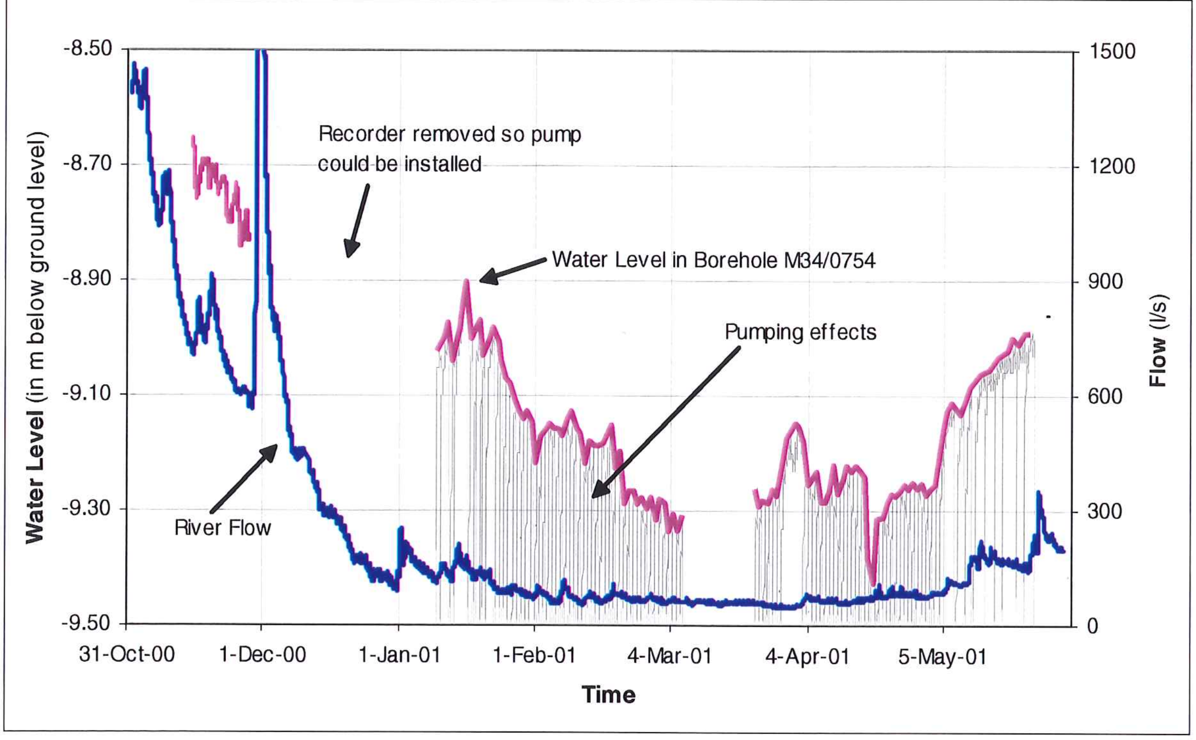


Figure 5-7 ***Water Level fluctuations in Borehole M34/0754 on the left bank of the Lower Waipara River, November 2000 to May 2001, compared with flow in the Waipara River at White Gorge.***

Recorders were also placed in boreholes M34/0690 and M34/0662 to assess the effects of pumping from the surrounding wells and boreholes. Both boreholes are situated on the Glasnevin Flats within recent subdivisions and are surrounded by numerous small (generally 5 ha) lifestyle blocks, that have their own boreholes which are pumped for domestic, stock and small scale irrigation water. Once again the water level was measured every 15 minutes using a Kianga pressure transducer connected to a Campbell 21X data logger.

Borehole M34/0690 situated off Georges Road, is 26.2 m deep and has a 4 metre screen set from 22.2 m to 26.2 m; while borehole M34/0662 is situated off Racecourse Road, is 23.0 m deep and is screened from 21.5 m to 23.0 m (refer to Appendix 5.3 for the borehole details). Both boreholes draw water from above the level of the Waipara River and water level data indicates that there is no connection with the river. Borehole M34/0690 was pumped over the monitoring period to supply irrigation water for 1400 olive trees while Borehole M34/0662 was not utilised.

Water levels in Borehole M34/0690 declined by over 3 m during the monitoring period (Figure 5-8). The rate of natural water level decline was increased approximately 10% with pumping every second day and approximately 20% by daily pumping. Within a 600 m radius of M34/0690 six other boreholes all of similar depth to M34/0690, are regularly pumped for domestic, stock and small scale irrigation water. Relatively small scale pumping (20 m^3) from boreholes over 125m from M34/690 resulted in induced drawdowns of approximately 0.7 m (Table 5-3), which highlights the limited storativity and transmissivity of the aquifers.

Table 5-3 Induced Drawdowns in Borehole M34/0690, Georges Road Glasnevin Flats.

Borehole Number	Distance to M34/0690 (m)	Pumping Regime	Effect on Borehole M34/0690 namely Drawdown (m)
M34/0691	50	Initially the same as M34/0690 then every day	Identical to pumping M34/0690 itself i.e. drawdowns greater than 4 m .
M34/0689 M34/0688 M34/0686	125 250 500	Every second day opposite to M34/0690 Every Day Every second day opposite to M34/0690	Combined effect of a drawdown of approximately 0.7m
M34/0687 M34/0692	440 560	The same as M34/0690 The same as M34/0690	Can not determine effects

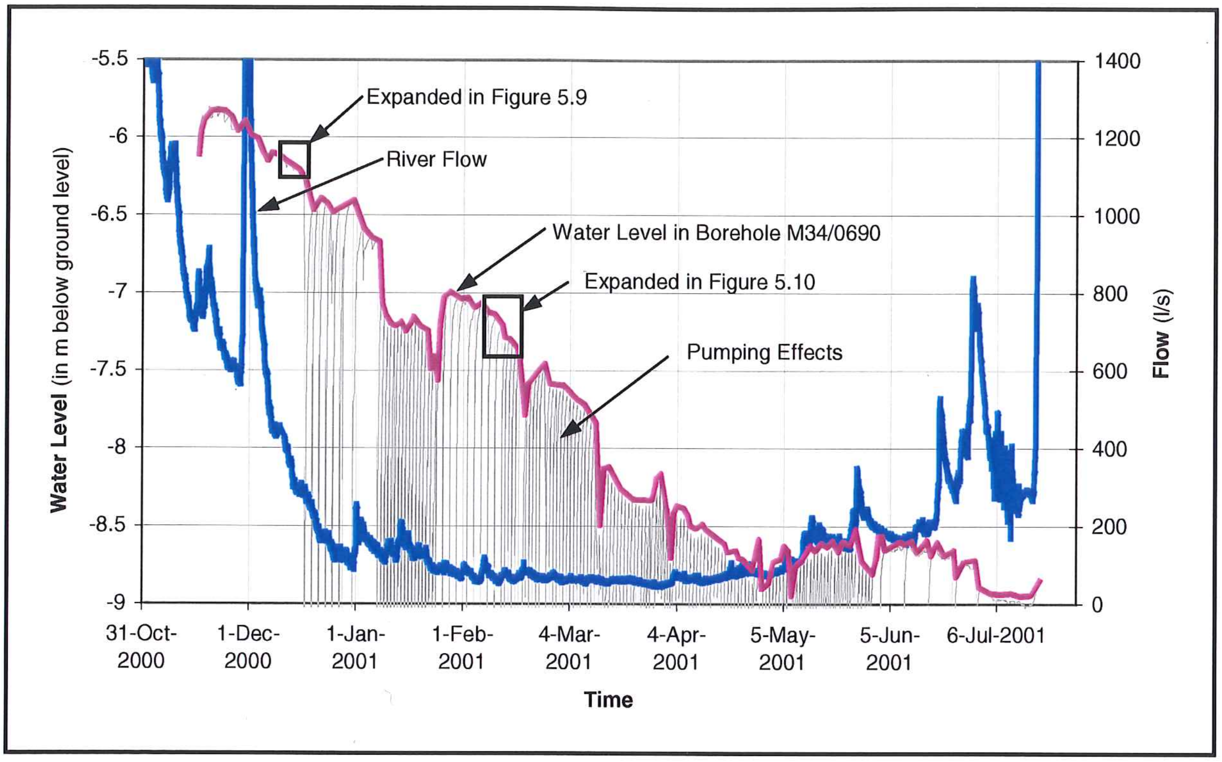


Figure 5-8 ***Water Level fluctuations in Borehole M34/0690, Georges Road, Glasnevin Flats, November 2000 to July 2001.***

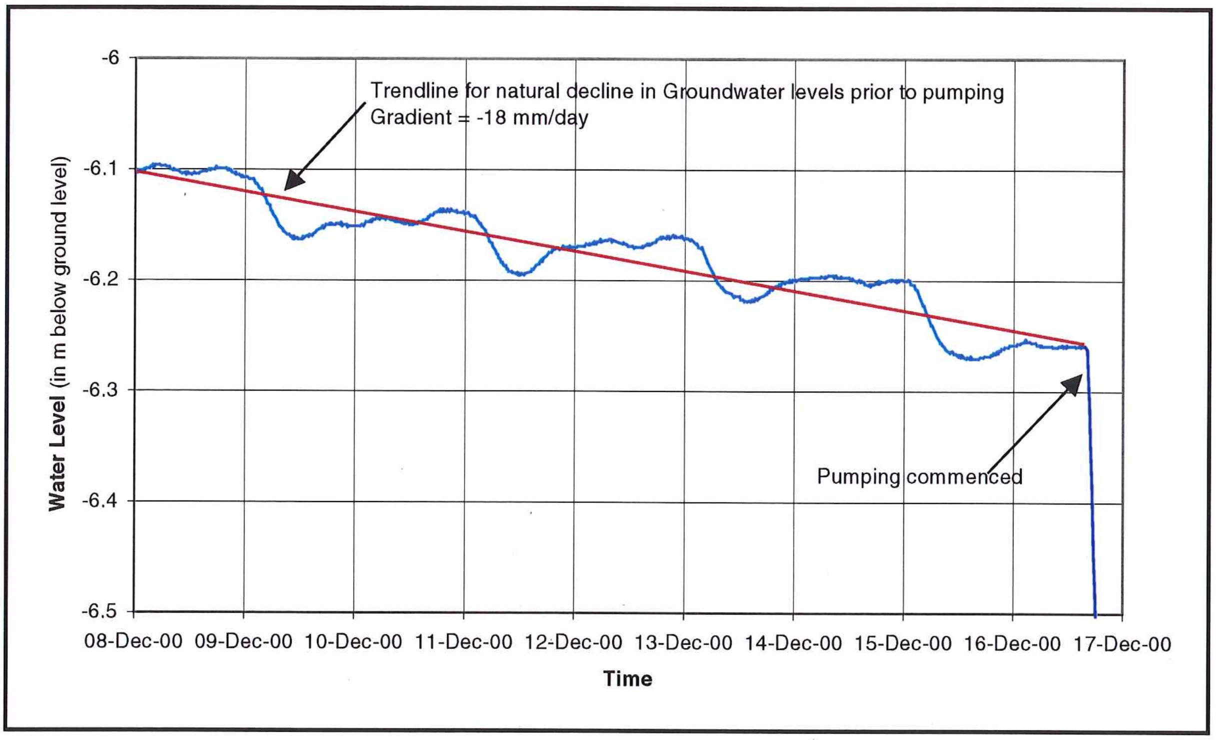


Figure 5-9 ***Water Level Fluctuations in borehole M34/0690, Georges Road, Glasnevin Flats, from 8 December 2000 to 17 December 2000***

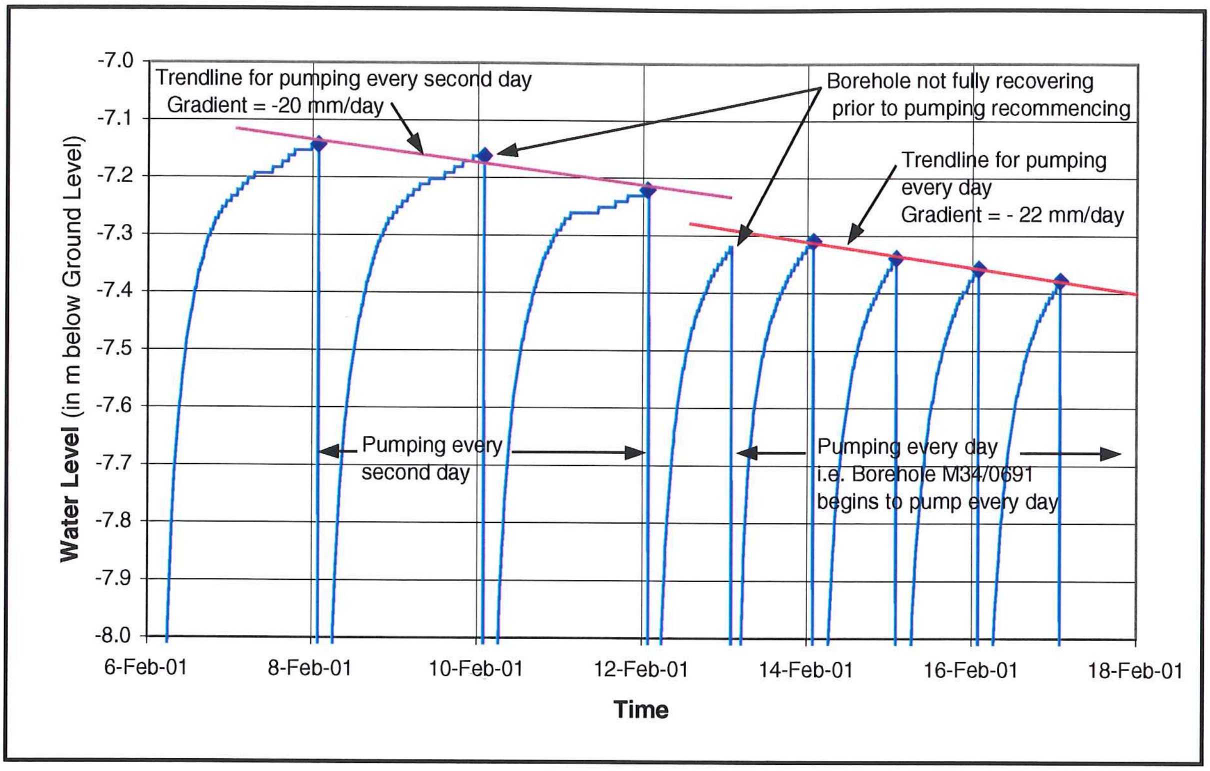


Figure 5-10 Pumping induced Drawdowns in borehole M34/0690 Georges Road, Glasnevin Flats, from 6 February 2001 to 18 February 2001

Water levels in Borehole M34/0662 fluctuated over a 7 m range during the monitoring period (Figure 5-11). Pumping effects dominated the monitoring period with water level being continuously drawn down by surrounding pumping, and it was only at the end of the irrigation season in late May and early June 2001 that the water level stabilised to a natural level. There are a total of 12 existing wells and boreholes situated within 500 m of M34/0662, the majority of which draw water from a similar depth. Of the 12 boreholes, one is pumped regularly for the irrigation of an olive grove, five are pumped intermittently for domestic supply, stock water and small scale (< 0.5 ha) irrigation, with the remaining six currently unused.

Water level data from M34/0662 indicates that intermittent domestic pumping from boreholes results in a drawdown of generally less than 1 m, but which can reach up to 2 m if pumping from two or more boreholes coincides. Borehole M34/0660 which is 230 m north of M34/0662 is pumped each night to irrigate a 5 ha olive grove. The effects of this pumping are readily seen in the water level data (Figure 5-11) with an approximately 2m drawdown occurring in M34/0662. The frequency of pumping prevents recovery of the water level and results in the water level being held at an artificially low level. When this regular pumping coincides with the intermittent pumping, large drawdowns occur (up to 4.5 m) and the water level is then held at the lower level by the regular pumping of M34/0660.

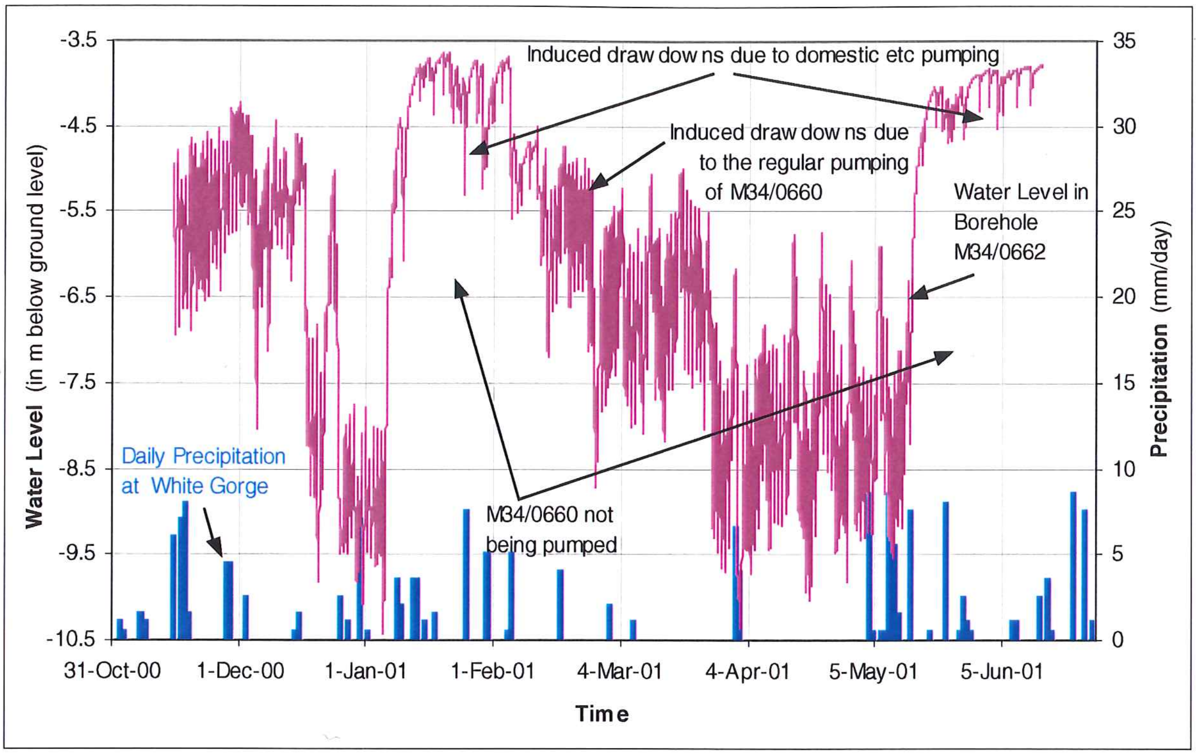


Figure 5-11 ***Water Level Fluctuations in Borehole M34/0662, Racecourse Road, Glasnevin Flats, November 2000 to June 2001***

The relatively large induced drawdowns and slow recovery rates of boreholes M34/0690 and M34/0662 indicate that the aquifers which both boreholes tap have low storativity and transmissivity, which confirms the findings of Loris (2000). It is noted that in both cases the abstractions from the surrounding boreholes fall within Environment Canterbury's permitted use rules (Section 5.3.4 B), do not require a resource consent and therefore are not assessed in terms of their effects on neighbouring boreholes. Both boreholes are situated in relatively new subdivisions and water use is expected to increase significantly as the subdivision develops and all the lots are built on. This will increase the induced drawdowns and has the potential to cause conflict between water users.

5.3.4 WATER USE

Historically, groundwater provided a significant proportion of the domestic and stock water requirements of the area. Most of the older properties have either hand-dug, brick lined wells or shallow boreholes, and numerous windmills used to be present particularly in the Omihi Valley and on the Glasnevin Flats. With the construction of the Rural Water Supply Schemes in the 1960s and 1970s many of historic groundwater abstractions were no longer required and many wells, boreholes and windmills fell into disrepair. Groundwater was traditionally considered a limited resource in Waipara and it was felt that groundwater would not provide a suitable source of irrigation water (Wilson, 1963; Borrie et al., 1972).

It was not until 1996 when Canterbury House Vineyard drilled two wells on their property south of the Waipara River and found partially flowing artesian water at a combined yield of 17 l/s, that the potential of groundwater to supply irrigation water was realised. Between January 1996 and June 2001, Environment Canterbury issued 58 Bore Permits authorising the drilling of numerous wells within the Waipara Catchment and on the Glasnevin Flats. With both the Rural Water Supply Schemes and the surface water resources of the catchment already heavily allocated, many landowners are now moving their attention to groundwater as a source of both irrigation and domestic water.

(a) ABSTRACTIONS AUTHORISED BY RESOURCE CONSENTS

On 1 June 2001 the Environment Canterbury consents database contained 24 current consents authorising the abstraction of groundwater in the Waipara Area (Table 5-5). Four of the consents are for domestic or public water supply with the other 20 being for irrigation. The consents allow abstraction year round although the irrigation abstractions are generally only exercised during the dry summer months. Over the 2000-2001 summer six of the consents were not exercised due to incomplete infrastructure (namely vines not planted or pumps and irrigation systems not installed).

The current consents allow a total of 20019 m^3 of groundwater to be abstracted per day at a maximum rate of 307 l/s. Of this 2006 m^3 (23 l/s) is taken from shallow wells and galleries in the bed of the main Waipara River and should be considered surface water takes (Section 4.2.8). During the 2000-2001 summer actual groundwater usage was 42% of the allocated volume indicating that allocation often exceeds need. Actual groundwater usage in both the lower Omihi Valley and on the Glasnevin Flats was significantly less than the allocated volume with only 6% and 5% of the allocated volume being utilised respectively, Table 5-4.

Table 5-4 ***Comparison between Consented Groundwater Abstractions and Actual Groundwater Usage in the Waipara Area over the 2000-2001 summer.***

Area	Consented Abstractions	Consents Exercised 2000-2001[1]		Actual use 2000-2001[1]	
	m^3/day	m^3/day	% of Total Allocated	m^3/day	% of Total Allocated
Upper Omihi Valley	7515	7515	100	3279	44
Lower Omihi Valley	890	582	65	53	6
Home Creek	2739	2739	100	1287	47
Waipara Township	981	977	99.6	247	25
Waipara River	5317*	4781	90	2670	50
Glasnevin Flats	571	130	23	30	5
Total	**18013**	**16723**	**94**	**7565**	**42**

*excludes two takes from the bed of the Waipara River

[1]Information obtained from interviews with consent holders.

Table 5-5 Current Water Permits for Groundwater Abstractions in the Waipara Area as at 1 June 2001

Permit Holder	Area	Consent Number	Max. Rate L/s	Max. Daily m^3	Purpose	Expiry Date
Gould D.C.	Home Creek	CRC992691	18	1555	Spray irr pasture/crop	2034
Netherwood Trust	Home Creek	CRC001363	14	1184	Spray irr pasture/crop	2035
Total	**Home Creek**		**32**	**2739**		
Hull F.T.L. & E.M.	upper Omihi Valley	CRC010647	0	25	Trickle irr grapes	2035
Netherwood Trust	upper Omihi Valley	CRC000047*	72	6221	Spray irr pasture/crop	2034
Omihinui Farm Ltd	upper Omihi Valley	CRC991435	15	1269	Spray irr pasture/crop	2034
Total	**Upper Omihi Valley**		**87**	**7515**		
Black R.G & K.	lower Omihi Valley	CRC000056	8	384	Trickle irr grapes	2034
Cabal Properties Ltd	lower Omihi Valley	CRC010755	8	154	Trickle irr grapes	2034
Kitson G.W. & N.M.	lower Omihi Valley	CRC010754	8	77	Trickle irr grapes	2034
Litchfield Nominees No 14	lower Omihi Valley	CRC010756	8	77	Trickle irr grapes	2034
Stackhouse K.W.	lower Omihi Valley	NCY800640	2	198	Domestic Water	2001
Total	**Lower Omihi Valley**		**34**	**890**		
Ashmore A.A.	Waipara Township	CRC900300	1	9	Glasshouse Irrigation	2004
Hurunui District Council	Waipara Township	NCY800767	0	4	Not Used	2001
Hurunui District Council	Waipara Township	CRC002019	4	190	Public Water Supply	2035
Pollard P.J. & 14 others	Waipara Township	CRC900760A	9	21	Domestic Water	2004
Pollard P.J. & 14 others	Waipara Township	CRC900760B	28	757	Trickle irr grapes	2004
Total	**Waipara township**		**42**	**981**		
Amberley Golf Club	River mouth	NCY870085	30	918	Spray Irr golf course	2004
Bakker C. & J.D	Teviotdale Bridge	CRC991554	2	62	Spray Irr flowers	2034
Canterbury House	Lower Waipara	CRC980403	21	1814	Trickle irr grapes	2032
Ensor T.H. & D.H.	mid Waipara River	CRC010514	6	536	Trickle Irrigation	2035
Penhaligon Holdings	Upper Waipara	CRC001645	23	1987	Trickle irr grapes	2035
Renowden G.	White Gorge	CRC992499[1]	1	86	Trickle irr trees	2034
Tutton, Sienko & Hill	Upper Waipara	CRC920498[1]	22	1920	Trickle irr grapes	2004
Total	**Waipara River**		**82[a]**	**5317[a]**		
Viman Investments Ltd	Glasnevin Flats	CRC940678	5	441	Domestic & Irrigation	2028
Welsh & Ferguson	Glasnevin Flats	CRC971720	2	130	Spray Irr pasture	2032
Total	**Glasnevin Flats**		**7**	**571**		
Grand Total			**284**	**18013**		

[1] Considered surface water takes [a] excludes [1]

(b) *PERMITTED USE ABSTRACTIONS*

Environment Canterbury's current Regional Plan permits (permitted use) the abstraction of small quantities of groundwater as follows:

'Water may be taken from any groundwater resource under the following circumstances:

- *Up to 20 m^3 per property per day may be taken, provided: the bore is further than 50 m from any bore on a neighbouring property and; any surface water resource.*
- *Up to 100 m^3 per property per day may be taken (at rate not exceeding 10 l/s), provided: the abstraction occurs on a property greater than 20 ha in size and; the bore is further than 100 m from any other abstracting bore or any surface water resource.' (Environment Canterbury, 2000, p10).*

Of the 146 wells and boreholes visited during the potentiometric surveys, 86 (59%) are currently used to abstract groundwater under the permitted use rules, 8 (5%) are covered by resource consents, with the remaining 52 currently not utilised. During landowner interviews conducted as part of this study, it was found that approximately 2300 stock units (4%) and 27 (12%) houses obtain their water requirements from permitted use groundwater abstractions. Of the approximately 1300 ha currently irrigated in the area, 37 ha (mostly small olive groves, orchards and vineyards) are irrigated from permitted use groundwater abstractions. Using a domestic allocation rate of 900 l per household per day (Hurunui District Council rural water supply scheme allocation rate), a stockwater requirement of 3 l per stock-unit (Fleming, 1996) and assuming an irrigation rate of 10 m^3 per ha per day (interviews with various olive and grape growers in the area), an estimated volume of 400 m^3 per day is abstracted under the permitted use rules. This is equivalent to 2% of the volume of groundwater that is allocated via resource consents.

5.4 GROUNDWATER RECHARGE

Recharge of a particular aquifer can occur via three main mechanisms:

- the infiltration of precipitation down through the soil profile into the aquifer;
- seepage of water through the bed of rivers and creeks into the aquifer; and
- groundwater movement between aquifers.

(Fetter, 1994).

5.4.1 PRECIPITATION INFILTRATION

The Canterbury Teviotdale Gravels cover approximately 13700 ha within the Waipara Alluvial Basin. Thornthwaite Water Balances conducted at four rain-gauge sites situated within the basin indicate that of the 680 mm of average annual precipitation only, 233 mm is available for either surface water runoff or infiltration to groundwater (Table 5-6). Based on flow measurements from Omihi Stream and Home Creek (Chapter 4.2.7) runoff from the whole of the Waipara Alluvial Basin is estimated at 106 mm ± 10%. This suggests an annual infiltration of precipitation of 116–138 mm which equates to between 16 and 19 million m^3 of water. This is considered a maximum as it does not consider surface water flow out of the Glasnevin Flats via the numerous perennial drains which discharge into the Kowai Catchment.

Table 5-6 ***The Results of 1951-2000 Thornthwaite Soil Water Balances for various site in the Waipara Alluvial Basin***

Site Name and Number	Area	Precipitation P	Actual Evapo-transpiration ET_A	Soil Water Surplus (runoff + infiltration)
		mm	mm	mm
Amberley H32171	Southern end of the Glasnevin Flats	662	437	225
Baxters Glenrose H4420	Upper Omihi Valley	689	443	246
Stackhouses W04	Mid Omihi Valley	745	483	262
Waipara Whytes H32072	Waipara Township	625	429	197
Average		**680**	**448**	**233**

Thick clay fragipans within the soil profile (Chapter 2.4) restricts the infiltration of precipitation over large areas of the catchment with water tending to pool and flow along the upper surface of the fragipan. This flow of water is visible in the gravel pits on the Glasnevin Flats during and immediately following heavy rainfall events.

Aquifer tests undertaken on the Glasnevin Flats indicate that aquifers at a depth of 20 m are confined to semi-confined (Loris, 2000) and it is expected that the unconfined section of the Waipara aquifer system is limited to the upper approximately 10 m. Infiltration of precipitation past the unconfined aquifer will be limited due to the presence of numerous low permeability layers and the low transmissivity, storativity and hydraulic conductivity of the aquifers (Loris, 2000). Water dating undertaking by Loris indicated that recharge to the 11.8 m deep well M34/0677 (situated between Purchase Road and Inns Road on the Glasnevin Flats) takes approximately 12 years.

5.4.2 River Losses to Groundwater

Detailed instantaneous gauging data collected as part of this study identified surface flow losses where the Upper Waipara River and Weka Creek flow over Tertiary rock units and where the Weka Creek, Omihi Stream and Home Creek flow over the Canterbury Teviotdale Gravels.

(a) River Losses to the Tertiary Rock Units

Approximately 20 l/s of flow is lost from the Upper Waipara River between the confluence of the Middle Branch and the confluence of the Southern Branch. Through this section the river flows essentially parallel to the eastern limb of the Macdonald Syncline and crosses numerous sub vertical beds from the Mount Brown Formation through to the Conway Formation. The Weka Creek loses approximately 8 l/s immediately upstream of Ferguson

Road were the creek flows over the same beds which are on the western limb of the Waipara Syncline and which dip towards the east (downstream) at approximately 30^0. The Waipara River crosses these beds again between Laidmore Road and White Gorge. Instantaneous gauging data indicates that despite the inflow of five small tributaries there is only a very slight increase in flow over this section. This suggests possible groundwater losses, although the lack of detailed gauging data prevents conclusive comment.

Numerous sinkholes exist where these beds outcrop on the Black Anticline (Loris, 2000), in the vicinity of Mount Cass and near White Gorge. Landowner interviews revealed that during heavy rain significant volumes of surface water flow into these sinkholes and essentially disappear. It is proposed that a bed or possibly a number of beds within the Mount Brown to Conway Formation are permeable and contain significant quantities of water. In addition to recharge from the sinkholes, the Upper Waipara River and Weka Creek, a large number of small tributaries cross these beds creating a potentially significant recharge source.

(b) River Losses to The Canterbury Teviotdale Gravels

Flow data for the lower Waipara River between White Gorge and the Omihi Stream confluence indicates that the river is predominately gaining flow (Chapter 4.3.2). Significant recharge of the gravel aquifers of the Waipara Alluvial Basin from seepage from the lower Waipara River is therefore unlikely which concurs with the findings of Loris (2000).

Flow data indicates that large sections of Omihi Stream and the lower sections of both Weka Creek and Home Creek are strongly connected to the area's groundwater. In Weka Creek significant flow losses occur below the Glenmark Irrigation Scheme intake structure where the creek flows over the Canterbury Teviotdale Gravels. Losses of 80 l/s, 30 l/s and 15 l/s were recorded on 28 September 2000, 15 January 2001 and 3 April 2001 respectively. While there is usually surface flow immediately below the intake structure, surface flow only occurs at the State Highway 7 Bridge during the wet winter months or immediately following large storm events.

Home Creek (Glenmark Stream) gains much of its summer base flow from the discharge of numerous springs between Glenmark Drive and Kings Road. This flow is quickly lost below Kings Road, particularly over the 3 km length of stream bed between Kings Road and the Railway Line. A loss of 36 l/s was recorded over this section on 3 April 2001. The springs occur in areas mapped as Kowai Gravels (Jongens, 2000) while the losses occur where the streambed changes to Canterbury and Teviotdale Gravels.

Heiler et al. (1977) found that during high flows in Omihi Stream a significant proportion of flow leaves the active channel and recharges shallow groundwater in the recent alluvial gravels that flank the stream. Instantaneous gauging data collected as part of this study confirmed this, with a loss in flow of over 50 l/s being recorded on 10 October 2000 over the 3 km section between Baxters Road and Braeburn Pastures. During the summer months, surface flow ceases over large sections of Omihi Stream and the numerous deep ponds along the streambed are fed by this shallow groundwater system.

Omihi Stream gains significant quantities of flow from the discharge of springs over the 3 km stretch between the confluence of Home Creek and the Glenray Farm Bridge. A gain of approximately 150 l/s was recorded on the 5 April 2001. Oxygen-18 analysis undertaken by Loris (2000) indicated that the springs have a similar recharge source as Home Creek. It is suggested that downstream of Kings Road, Home Creek flows via numerous old buried channels and reappears as surface flow via the springs at Glenray. Similar mechanisms are suggested for both Omihi Stream and Weka Creek. The substantial springs above Glenray Bridge therefore represent discharge from old buried channels of Omihi Stream, Home Creek and Weka Creek.

In addition to losses from the main channels of Weka Creek, Home Stream and Omihi Stream, losses from their numerous tributaries are expected. Observations from Smothering Gully (a tributary of Omihi Stream) support this in that the creek runs perennially where it crosses State Highway 1 but dries before its confluence with Omihi Stream (a distance of < 2 km). Losses from Omihi Stream, Home Creek, Weka Creek and their tributaries provide a mechanism for rapid and significant recharge of the unconfined and shallow confined aquifer system adjacent to these streams.

5.4.3 GROUNDWATER MOVEMENT BETWEEN AQUIFERS

The aquifer system of the Waipara Alluvial Basin consists of small semi-permeable to permeable old buried stream and river channels within extensive clay bound gravels of low permeability. The presence of the clay bound gravels results in the aquifers being confined or semi-confined. The extensive clay bound gravels and the very low transmissivity, storativity and hydraulic conductivity of the aquifers restricts the vertical and lateral flow of groundwater (Loris, 2000), and the movement of groundwater between aquifers will be extremely slow. Water dating indicated that residence times for most of Waipara's groundwater is in excess of thirty years confirming the slow recharge rate (Loris, 2000).

Groundwater chemistry and dating suggests that recharge of the gravel aquifers is predominantly by downward percolation of both precipitation (Loris, 2000) and river water. It is also proposed that some upward movement of groundwater occurs along fault and fracture lines particularly in the Omihi Valley. This is consistent with the chemical analysis of the groundwater which indicated that the groundwater in the Omihi Valley is very hard and has high concentrations of total dissolved solids (Loris, 2000). The high yields obtained from a number of the areas boreholes and the high artesian heads that are experienced, can be explained by these boreholes tapping aquifers that are partially recharged via upward movement of groundwater.

5.4.4 CONCEPTUAL GROUNDWATER RECHARGE MODEL

Infiltration of precipitation is the dominant mechanism for recharge of the upper gravel aquifers, while seepage from the areas watercourses and the upward migration of deep groundwater are the dominant recharge mechanisms for the deeper gravel aquifers (Figure 5-12). Recharge of the aquifers along the northwest edge of the valley (in the vicinity of the current channel of Omihi Stream) is expected to be substantial higher than recharge to the aquifers in the central and eastern parts of the valley due to seepage from Omihi Stream.

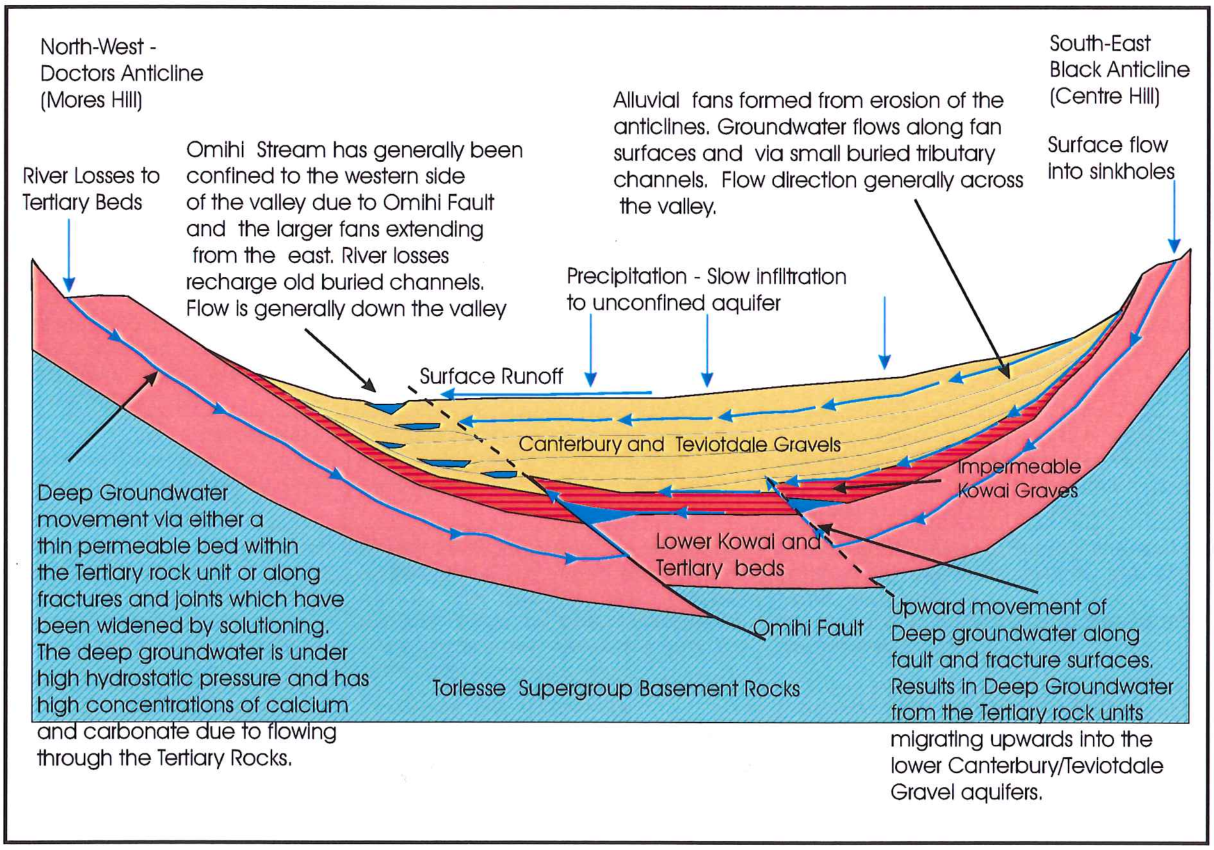


Figure 5-12 Conceptual Model for Recharge to the Aquifers of the Omihi Valley, Waipara (viewed looking up the valley).

5.4.5 RECHARGE CATEGORIES

There is significant variation in recharge of the gravel aquifers of the Waipara Alluvial Basin allowing 7 broad categories to be defined (Table 5-7). The approximate spatial distribution of the 7 categories is highlighted in Figure 5-13. Of the seven categories only two, the unconfined aquifers in the Recent gravel deposits and the confined and semi-confined aquifers adjacent to Home Creek, Omihi Stream, and Weka Creek (Zone 2 Figure 5-13), are expected to have significant recharge. The aquifers in the Recent gravels are directly connected to surface flow in the areas watercourses and abstractions should be considered surface water abstractions. The aquifers adjacent to Home Creek, Omihi Stream, and Weka Creek receive significant recharge via seepage from the three watercourses and have the best potential for future groundwater development. Gauging data (Chapter 4.2.3) indicates flow losses from the three watercourses are approximately 170 l/s during the winter and 80 l/s over the summer.

Table 5-7 Recharge Categories for the Aquifers of the Waipara Alluvial Basin.

Aquifer Category	Recharge source	Characteristics
Aquifers within Recent Gravel deposits in the current flood plains of the areas rivers and creeks	Surface water from the Waipara River, Weka Creek, Home Creek and Omihi Stream	Hydraulically connected to the surface water resources, accessed via galleries and shallow (<10m deep) wells
Unconfined Canterbury/Teviotdale Gravel Aquifer generally <10m deep throughout the basin	Precipitation	Recharge limited due to low rainfall and presence of fragipan, limited storage and naturally dries out in summer other than in the swampy areas south of Racecourse Road and along Stockgrove Road (Zone 5 Figure 5-13).
Confined and semi-confined Canterbury/Teviotdale gravel aquifers on the Eastern side of the Omihi Valley (Zone 1 Figure 5-13)	Downward seepage from the unconfined aquifer, tributary losses down fan surfaces and via buried tributary channels, possibly some minor upward recharge via fracture zones	Recharge is likely to be slow although it is noted a number of the tributaries are perennial and have significant catchments.
Confined and semi-confined Canterbury/Teviotdale gravel aquifers adjacent to Home Creek, Omihi Stream, and Weka Creek (Zone 2 Figure 5-13)	Significant river and tributary recharge, suspected recharge via upward movement along fracture zones.	Represents the best potential area for groundwater development. Potential for rapid recharge.
Confined and semi-confined Canterbury/Teviotdale gravel aquifers below the Waipara River (Zone 3 Figure 5-13).	Very limited infiltration of river water and the southward movement of groundwater from the previous zone.	Recharge relatively slow, is likely to improve downstream where groundwater movement from the previous zone is likely to be greater particularly below the State Highway Bridge.
Confined and semi-confined Canterbury/Teviotdale gravel aquifers on the Glasnevin Flats (Zone 4 Figure 5-13)	Downward seepage from the unconfined aquifer, some flow down fan surfaces around the Eastern and Western margins. Below the level of the Waipara River groundwater movement from the north under the river is likely	Recharge rates likely to be very low, and are expected to decrease towards the south. Some exceptions occur around the basin margins due to surface runoff flowing down fan surfaces.
Confined and semi-confined Canterbury/Teviotdale gravel aquifers on the flats between the Waipara River and Home Creek (Zone 6 Figure 5-13)	Insufficient data to determine	Expected to be similar to the Eastern Omihi Valley with some deeper groundwater movement from the north.

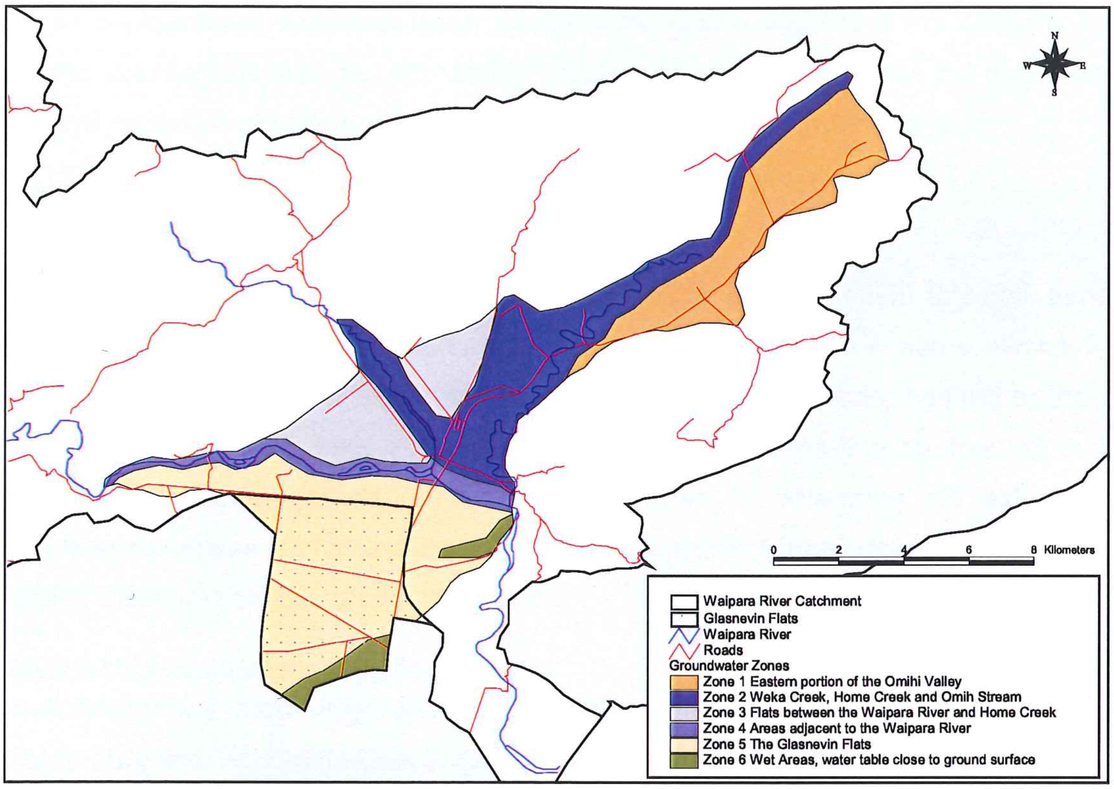


Figure 5-13 Groundwater Recharge Zones for the Waipara Alluvial Basin

5.4.6 OVERALL GROUNDWATER RECHARGE

Infiltration of precipitation during the winter months is expected to recharge the gravel aquifers of the Waipara Alluvial Basin by 16-19 million m^3 per year (Section 5.4.1). Flow losses in Weka Creek, Home Creek and Omihi Stream range from a minimum of 80 l/s to a maximum of 170 l/s (Section 5.4.2), which equates to an annual recharge of between 3 and 5 million m^3 per year. The total annual recharge to the gravel aquifers of the Waipara Alluvial Basin from infiltration and seepage is therefore estimated at between 19 and 24 million m^3 per year. Upward movement of deep groundwater is also expected to recharge the gravel aquifers (Section 5.4.3); however there is currently no data to confirm this.

The potentiometric surveys indicated that over the 2000-2001 summer the volume of groundwater stored in the gravel aquifers of the Waipara Alluvial Basin decreased by an estimated 7 million m^3 of water. The decrease is attributed to a combination of groundwater use and natural summer decline in groundwater storage due to spring discharges and groundwater contributions to surface water flow. Actual groundwater use over the 2000-2001 summer was estimated at 7965 m^3/day (7565 m^3/day from consented takes and 400 m^3/day from permitted use abstractions, Section 5.3.4), which equates to 1.4 million^3 being extracted between the two potentiometric surveys of. This suggests that the natural summer decline in groundwater storage is approximately 6 million m^3 or between 25 % (24 million m^3 recharge) and 32 % (19 million m^3 recharge), of estimated annual recharge. To prevent a long-term decline in the volume of water stored in the gravel aquifers of the Waipara Alluvial Basin, the volume allocated for abstraction should not exceed 13 million m^3 (the minimum estimate of recharge 19 million m^3 less natural summer decline 6 million m^3).

5.5 SUMMARY

The known groundwater resources of the Waipara catchment are limited to small, generally low yielding aquifers in the clay bound gravel deposits which infill the Waipara Alluvial Basin. The high level of allocation of summer flows in the area watercourses, has led to the rapid development of these aquifers as landowners looked for alternative sources of summer irrigation water. Investigations have been undertaken to determine the extent of the groundwater resources and to assess their ability to sustain further development. The key findings of these investigations are:

Hydrogeology and description of the Aquifers:

- Historically the search for groundwater in Waipara has focused on the aquifers within the Canterbury and Teviotdale Gravel deposits which infill the Waipara Alluvial Basin.
- The aquifers consist of relatively small semi-permeable to permeable old buried river channels within the clay bound gravel deposits. The aquifers are of limited thickness (generally <10m), are not laterally extensive, do not transmit water very fast (transmissivity 18-92 m^2/day) and when pumped experience large drawdowns.
- Kowai Gravels underlie the Canterbury Teviotdale Gravels and consist of well compacted clay and silt bound gravels of low permeability and are not expected to contain significant economic aquifers.
- A recent borehole indicates that a deep groundwater exists within the Tertiary rock units which underlie the gravel deposits.

Existing Wells and Boreholes and Current Groundwater Use:

- Currently there are 277 wells and boreholes within the study area of which the majority are situated within the Waipara Alluvial Basin.
- Water yields are generally low with yield greater than 10 l/s the exception rather than the rule. Wells and boreholes that draw water from above the level of the Waipara River have low yield (< 3l/s) and yields generally tend to increase with depth.
- Water levels dropped by an average of 1.54 m over the 2000-2001 summer, which represented a decrease in groundwater storage of approximately 7.1 million m^3.
- Water level data indicates that the Waipara River is not significantly connected to the area's groundwater resources.
- Regular small scale pumping results in water levels in the new subdivisions on the Glasnevin Flats being held at an artificially lower level during summer. Boreholes in the

area have long recovery rates, generally do not fully recover between pumpings, and suffer significant interference effects and induced drawdowns.

- Current allocation of groundwater stands at 18 013 m^3 per day, of which 42% (7565 m^3/day) was actually used during the 2000-2001 summer which resulted in an estimated 1.4 million m^3 being abstracted over the 2000-2001 summer.
- An estimated 400 m^3 is abstracted per day under the current permitted use regulations.

<u>Groundwater Recharge:</u>

- Groundwater recharge throughout much of the area is extremely slow due to the low permeability of the clay bound gravels that dominate the area and the low transmissivity of the area's aquifers.
- Low precipitation, high evapo-transpiration rates and fragipans in the soil profile result in limited infiltration of precipitation which is essentially restricted to the unconfined aquifer.
- Significant river losses occur from Weka Creek, Home Creek and Omihi Stream and their tributaries. These flow losses recharge the adjacent aquifers.
- Evidence suggests significant volumes of water occur within the Lower Kowai or Tertiary beds that underlie the gravels. Upward movement of this deep groundwater along fault and fracture surfaces is expected to recharge some of the deeper aquifers in the gravels.
- Seven recharge categories are identified for the gravel aquifers of the Waipara Alluvial Basin of which only two, the unconfined aquifers in the Recent gravel deposits and the confined and semi-confined aquifers adjacent to Home Creek, Omihi Stream, and Weka Creek (Zone 2 Figure 5-13), are expected to have significant recharge.
- Total annual recharge to the gravel aquifers of the Waipara Alluvial Basin is estimated at between 19 and 24 million m^3 per year, of which 16-19 million is from infiltration of precipitation and 3-5 million m^3 is from seepage from Omihi Stream, Weka Creek and Home Creek.
- The natural summer decline in groundwater storage is approximately 6 million m^3 or between 25 % (24 million m^3 recharge) and 32 % (19 million m^3 recharge) of estimated annual recharge.
- To prevent a long term decline in the volume of water stored in the gravel aquifers of the Waipara Alluvial Basin the volume allocated for abstraction should not exceed 13 million m^3 (minimum recharge 19 million m^3 less natural summer decline 6 million m^3).

Given that recharge is limited over large sections of the Waipara catchment continued development of the area's groundwater resources has the potential to lead to over allocation. This issue is further investigated in Chapter 7 which looks at management of the water resources of the catchment.

6 WATER BALANCE AND RESOURCE SUMMARY

6.1 INTRODUCTION

This chapter contains two main themes: initially a water balance is completed and then a summary of the water resources of the Waipara Catchment is presented. The water balance uses climate and surface water hydrology data to estimate net groundwater movement. This groundwater information is then combined with data from the previous chapters to produce a summary of the area's water resources under both summer and winter conditions. The summary is used in considering management options in Chapter 7.

6.2 WATER BALANCE FOR THE WAIPARA CATCHMENT.

6.2.1 INTRODUCTION AND PREVIOUS WORK

The water balance for a catchment is essentially a study of the principle of the conservation of mass (in this case water) for that catchment. Simply put *"the water that flows into a catchment must either flow out or be stored within the catchment"* (Clausen and Spigel, 1999, p1-4). The use of water balance calculations is a longstanding and well recognised hydrological method. In most water balance studies all the elements of the water balance other than evapo-transpiration are measured or otherwise estimated and evapo-transpiration is calculated as the residual. Rosenberg et al. (1983) found that when water balances are applied to large areas accurate spatial averaging of inputs and outputs becomes difficult due to variations in rainfall over large areas and the lack of homogeneity in topography and soils.

In New Zealand water balance studies have been undertaken to both describe catchments (Toebes and Palmer, 1969; Toebes and Morrissey, 1970) and to highlight the effect of land-use change (Dons, 1987; Campbell and Murray, 1991; Fahey and Watson, 1991; Rowe and Fahey, 1991). Horrell undertook a water balance for the Waipara Catchment in 1992, and found that net evaporation was 550 mm/yr. Horrell's water balance did not account for the flow of groundwater out of the catchment through the lower Waipara Alluvial Basin as identified by Loris (2000). In the water balance presented in this chapter, evapo-transpiration will be estimated using established equations, allowing groundwater loss from the Waipara catchment to be estimated as the residual of the water balance.

6.2.2 THE THEORY OF WATER BALANCES

The water balance equation for a hydrologic system is simply the equation for conservation of mass. Because water is practically incompressible, conservation of mass can be expressed as conservation of volume and the water balance for hydrological studies becomes:

$$I = O + \Delta S \qquad \text{or} \qquad I - O = \Delta S$$

where $I =$ the sum of all inflows namely precipitation (P), river inflow (Q_{in}), groundwater inflow (G_{in}) and water imported (R_{in}) into the catchment.

$O =$ the sum of all outflows namely evapo-transpiration (E), river outflow (Q_{out}), groundwater outflow (G_{out}) and water exported (R_{out}) from the catchment.

$\Delta S =$ the change in storage (groundwater and surface water) over a given period.

Using a topographic catchment with no river inflow and defining the terms $\Delta G = (G_{out} - G_{in})$ and $\Delta R = (R_{out} - R_{in})$ the above equation can be rewritten as:

$$P - E - Q_{out} - \Delta G - \Delta R = \Delta S$$

(Adapted from Clausen and Spigel, 1999, pp 2-4)

In undertaking the water balance consistent units must be used. It is convention that the quantities of each of the variables are given as depth per unit time mm/yr.

The majority of catchment water balances are completed for a given number of whole years. At the end of each winter the area's lakes, dams and wetlands will be full and groundwater will be at its highest level. As such there will be very little change in the volume of storage from the end of one winter to the end of the next. This allows the assumption that there is no change in storage (i.e. $\Delta S \approx 0$). In Waipara surface water storage is relatively limited (Chapter 4.5) and landowner interviews indicated that the majority of dams fill every year over winter. In terms of groundwater levels the only long term monitoring data available is from a shallow well in Waipara Township (M34/0058). Water level data from the well indicates that while water levels fluctuate from winter to summer they generally return to the same level at the end of winter Figure 6.1. The average water level in August is 4.99 m below ground (based on 18 readings with a range of 4.19m - 6.17m). Given that the water balance is being undertaken using average annual data over 50 years (1951-2000) the assumption that there is no change in storage will be valid.

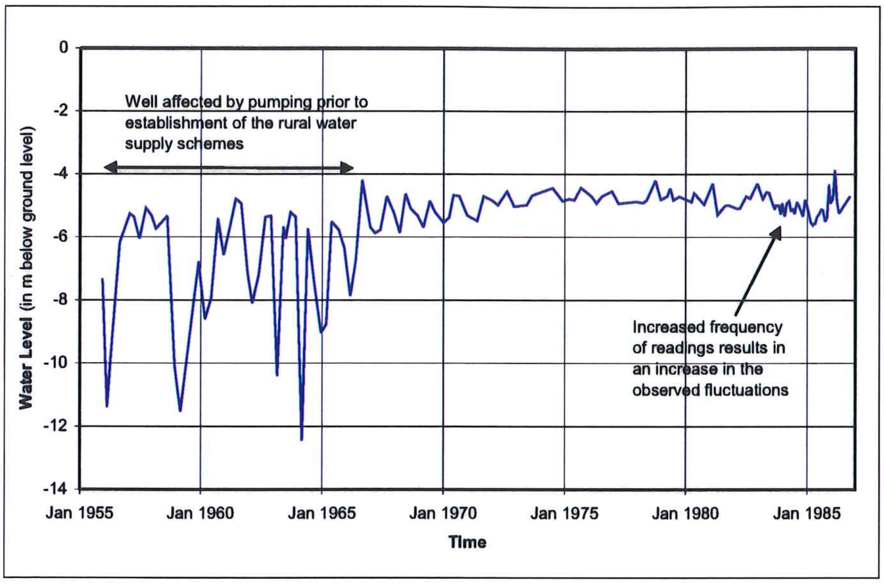


Figure 6.1 **Water Level Plot for Well M34/0058 in the Waipara Township December 1955 to October 1986**
(Data from Environment Canterbury's Wells database)

Of the variables that make up the water balance: precipitation, river outflow and net export of surface water are relatively easy to measure accurately. Conversely both net groundwater flow and evapo-transpiration are difficult to measure accurately. For the Waipara catchment, accurate data is available on precipitation (Chapter 3), river outflow (Chapter 4) and surface water imports into the catchment along with theoretical estimates of evapo-transpiration (Chapter 3) developed from climate data measurements taken at a number of sites in North Canterbury. Using these data the catchment water balance can be solved to determine net groundwater flow.

Potentiometric surveys undertaken by Loris (2000) indicate that groundwater flows out of the topographic catchment through the gravels of the Waipara Alluvial Basin in a south-southeast direction towards Amberley. Likewise, Horrell (1992) identified possible groundwater movement out of the catchment near Masons Flat. A water balance was established for the catchment in order to estimate the net groundwater movement.

6.2.3 INPUTS

Water inputs into the catchment consist of precipitation, water imported/piped into the catchment and groundwater flow into the catchment.

(a) PRECIPITATION

Catchment precipitation was determined using the Thiessen polygons method where the catchment was separated into fourteen areas (Figure 6.2), associated with the sites for which Thornthwaite soil water balances were undertaken in Chapter 3. This allowed the direct comparison of precipitation and actual evapo-transpiration.

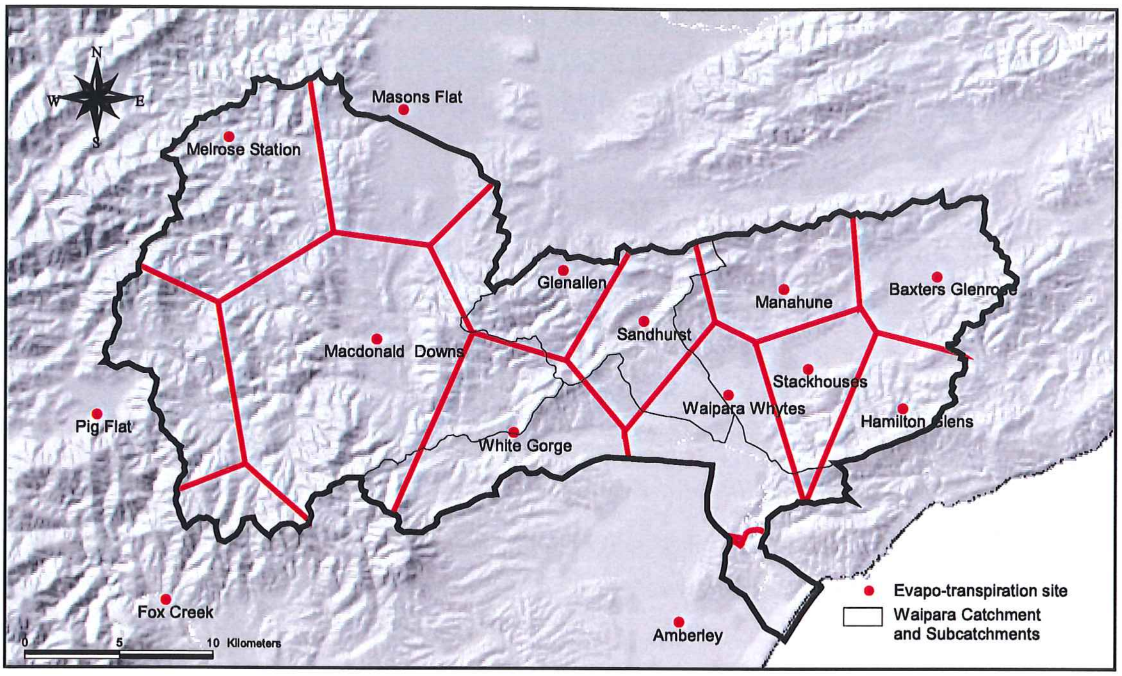


Figure 6.2 Thiessen polygons used for the Water Balance of the Waipara Catchment

Using the precipitation records from each site it was found that the total annual precipitation falling on the catchment is 540.5 million m^3 or 771 mm. The contribution from each of the areas is summarised in Table 6-1 below.

Table 6-1 1951-2000 Mean Annual Precipitation for the Waipara Catchment to the Teviotdale Recorder

Site	**Sub-catchment**	**Area** ha	**Area** %	**Annual Precipitation**		
				mm	10^6 m^3	% of Total
Fox Creek	Upper Waipara	1550	2.2	1052	16.3	3.0
Macdonald Downs	Upper Waipara	14176	20.2	738	104.6	19.4
Masons Flat	Upper Waipara	4838	6.9	762	36.9	6.8
Melrose	Upper Waipara	7675	10.9	964	74.0	13.7
Pig Flat	Upper Waipara	4828	6.9	935	45.2	8.4
Sub Total		33067	47.2	838	277.0	51.2
White Gorge	Mid Waipara	6777	9.7	667	45.2	8.4
Baxters	Omihi Stream	5002	7.1	689	34.4	6.4
Hamilton Glens	Omihi Stream	3215	4.6	947	30.4	5.6
Stackhouses	Omihi Stream	3274	4.7	745	24.4	4.5
Manahune	Home Creek / Omihi Stream	4253	6.1	758	32.2	6.0
Sub Total		15744	22.5	772	121.5	22.5
Glenallen	Weka Creek	4291	6.1	697	29.9	5.5
Sandhurst	Weka Creek	4439	6.3	688	30.5	5.7
		8730	12.4	693	60.5	11.2
Amberley	Lower Waipara	23	0.0	662	0.2	0.0
Whytes	Lower Waipara	5781	8.2	625	36.1	6.7
Sub Total		5804	8.3	625	36.3	6.7
Total	**Whole Catchment**	**70122**	**100**	**771**	**540.5**	**100**

Errors associated with catchment precipitation fall into two categories:

- Measurement errors, and
- Errors associated with estimating areal precipitation based on a number of point measurements.

Measurement errors, due to both aerodynamic effects (disturbed air flow over the top of the rain-gauges) and evaporation of collected precipitation, tend to reduce the amount of recorded precipitation. In both cases the errors are expected to be small due to the nature and positioning of the rain-gauges and the frequency of readings (Appendix 3.1).

The majority of the fourteen rain-gauges used to determine catchment precipitation are situated close to human activity at lower elevations and in valley floor positions with only three situated at an elevation of over 300 m. As such, catchment precipitation is likely to be underestimated as the records do not reflect hill top situations. Using the precipitation map established in Chapter 3 (Figure 3.3) which accounts for elevation the 1951-2001 mean annual catchment precipitation was estimated at 857 mm or 604 million m^3. While the precipitation map was not utilised for the water balance, it provides an estimate of maximum potential precipitation.

Given the above, the 1951-2000 mean annual precipitation for the Waipara Catchment is conservatively estimated at 771 mm ± 5 % with a potential maximum of 857 mm.

(b) IMPORT OF WATER

Of the five rural Water Supply Schemes operative in the Waipara Catchment, only the Waipara Township water supply scheme derives water from within the catchment. The other schemes source water from a combination of the Hurunui, Waitohi and Ashley Rivers.

The schemes were initially established in the 1960's by the local community and have subsequently been extended and upgraded. The lack of secure water sources in the Waipara Catchment was recognised during the development of the schemes; hence the decision to source water from outside the catchment. The schemes cover a large section of the catchment particularly the Omihi Valley, Waipara Flats, Masons Flat and the Weka Pass areas. A survey of landowners in the area (undertaken as part of this study) revealed that the rural water schemes supply 35% of the area's stock water requirements and 63% of the domestic water (excluding houses in the Waipara Township). Land owner interviews revealed that many properties rely on the schemes with approximately 15 000 ha and 115 000 stock units deriving stock water solely from the schemes. Without the schemes, the viability of a number of the properties in the areas would be seriously compromised.

Management of the schemes is now the responsibility of the Hurunui District Council. The schemes are run on a cost recovery basis with water allocated on a unit system where every house is allocated one unit (1800 l) per day and stock water is allocated at a maximum of 1 unit per 25 ha. The schemes are heavily allocated with very little spare water and a lengthy waiting list for either new connections or additional units.

A summary of the total water allocated via the schemes is shown in Table 6-2 below and shows that almost 900m^3 of water is imported into the catchment each day, which equates to 326000m^3 annually or 0.5mm/yr.

Table 6-2 The Rural Water Supply Schemes operative in the Waipara Catchment

Scheme Name	**Water Source**	**Volume allocated** (m^3 per day)*
Hurunui Lower Waitohi	Waitohi River	234
Hurunui Upper Waitohi	Waitohi River	356.4
Hurunui – Hurunui No 1	Hurunui River	149.2
Ashley Scheme	Ashley River	153.9
Waipara Township Supply	Groundwater	120 domestic connections
Total (ex Waipara Town Supply)		**893.5**

*Based on information obtained from the Hurunui District Council's Databases, 15 February 2001

The above volumes represent allocated water rather than actual water use and do not account for any leaks in the piping network. Given that landowners are billed on the water allocated, actual water use is expected to be similar to the allocated volumes especially during the summer months and the above volumes and are expected to be accurate to within 5%.

(c) Groundwater Inflow into the Catchment

Groundwater movement generally follows the dip of the geological strata. Almost all of the strata surrounding the Waipara Catchment dips away from the catchment and groundwater inflow is expected to be negligible. Given this, the net groundwater flow determined by the water balance will represent groundwater loss from the catchment.

6.2.4 Outputs

Water outputs from the catchment are made up of evapo-transpiration, river outflow and groundwater outflow. It is noted that there is no export of water out of the catchment. As previously outlined, the aim of this water balance is to estimate net groundwater movement for the catchment.

(a) EVAPO-TRANSPIRATION

As outlined in Chapter 3, Thornthwaite soil water balances were used to calculate actual evapo-transpiration rates for fourteen sites around the Waipara area. Annual actual evapo-transpiration rates ranged from approximately 430 mm near Waipara Township to over 530 mm in the coastal hills. Utilising Thiessen polygons (Figure 6.2) an estimate of mean annual 1951-2000 actual evapo-transpiration of 332.9 million m^3 or 475 mm was determined for the Waipara Catchment. The contribution from each of the areas is summarised in Table 6-3 below.

Table 6-3 1951-2000 Mean Annual Actual Evapo-transpiration for the Waipara Catchment

Site	**Sub-catchment**	**Area** ha	**Area** %	**Annual Actual Evapo-transpiration**		
				mm	10^6 m^3	% of Total
Fox Creek	Upper Waipara	1550	2.2	514	8.0	2.4
Macdonald Downs	Upper Waipara	14176	20.2	451	64.0	19.2
Masons Flat	Upper Waipara	4838	6.9	508	24.6	7.4
Melrose	Upper Waipara	7675	10.9	521	40.0	12.0
Pig Flat	Upper Waipara	4828	6.9	495	23.9	7.2
Sub Total		33067	47.2	485	160.4	48.2
White Gorge	Mid Waipara	6777	9.7	445	30.2	9.1
Baxters	Omihi Stream	5002	7.1	443	22.1	6.6
Hamilton Glens	Omihi Stream	3215	4.6	536	17.2	5.2
Stackhouses	Omihi Stream	3274	4.7	483	15.8	4.7
Manahune	Home Creek / Omihi Stream	4253	6.1	495	21.1	6.3
Sub Total		15744	22.5	484	76.2	22.9
Glenallen	Weka Creek	4291	6.1	459	19.7	5.9
Sandhurst	Weka Creek	4439	6.3	471	20.9	6.3
		8730	12.4	465	40.6	12.2
Amberley	Lower Waipara	23	0.0	437	0.1	0.0
Whytes	Lower Waipara	5781	8.2	429	24.8	7.4
Sub Total		5804	8.3	429	24.9	7.5
Open water evaporation		44		1392	0.6	0.2
Total	**Whole Catchment**	**70122**	**100**	**475**	**332.9**	**100**

Errors associated with evapo-transpiration from the catchment fall into two categories:

- Errors associated with determining Actual Evapo-transpiration at a particular site, and
- Errors associated with estimating catchment evapo-transpiration based on a number of point measurements.

The Thornthwaite soil water balances utilised monthly precipitation and Priestley Taylor potential evapo-transpiration data in conjunction with soils data to determine actual evapo-transpiration at 14 sites in the Waipara area. Potential errors in the measurement of precipitation (discussed earlier) tend to underestimate precipitation which will limit actual evapo-transpiration during period of climatic deficit.

The Priestley Taylor model for evapo-transpiration (Priestley and Taylor, 1972) utilises easily measured climatic data to predict potential evapo-transpiration and has been successfully applied in many areas (German, 2000). The model is based on the two most important ET factors: temperature and solar radiation. The model is semiempirical in nature and contains an empirically derived constant which relates to evaporation over a free-water surface or a dense well watered canopy. Fisher (2001) compared five evapo-transpiration models against data measured from a six-year-old ponderosa pine forest ecosystem in Northern California, U.S.A. and found that while the Priestley Taylor model slightly overestimated evapo-transpiration it was the most accurate model despite its relative simplicity.

The potential evapo-transpiration data used for this study was obtained off the NIWA Climate Database and was calculated assuming low vegetation such as pasture or crops. Evapo-transpiration from forested areas is higher than that of pasture catchments due to their taller structure, reduced aerodynamic resistance, greater ability to intercept precipitation and their ability to draw water from greater depths during droughts (Fahey and Rowe, 1992). During the Purukohukohu catchment study in the central North Island (N.Z.), Dons (1987) found that annual evaporation was 270mm lower for a pasture catchment than it was for an adjacent catchment in pines. Similarly Smith (1987) found that at Berwick in East Otago (N.Z.) annual evaporation in a pastured catchment was 293mm less than for an adjacent catchment of 14-year-old pines. Approximately 11 % of the Waipara catchment is vegetated in indigenous forest, native forest or riparian willows with a further 10% covered in scrub. Using Priestley Taylor potential evapo-transpiration data calculated for low vegetation will result in evapo-transpiration being underestimated in areas covered with taller vegetation.

The Priestley Taylor method also does not incorporate the effects of wind and in areas where wind is an important factor, the Priestley Taylor method tends to underestimate potential evapo-transpiration ET_P (Rosenberg et al., 1983). This is potentially of concern as the Waipara area often experiences hot dry winds from the north-west during the summer months. As the Thornthwaite soil water balances were undertaken using monthly data averaged over a minimum of 12 years, the effects of wind would be somewhat reduced due to the averaging process. Likewise the water balance was undertaken on an annual basis further reducing any errors associated with the actual evapo-transpiration data.

While the soils in the area have been mapped in reasonable detail (Chapter 2), accurate measurements of their available water capacity are limited. Available water capacity for each soil units was estimated from assessing the soil profiles to determine rooting depth and then standard available water values outlined in New Zealand Standard NZS5103 (1973). The rooting depth was taken as the lesser of: the depth to the top of any barriers to root growth (namely fragipan layers), the depth to the bottom of the B Horizon or 1200 mm. While this is considered appropriate for improved pasture, native grasslands and shallow rooting scrub and tussock land, it is conservative in that many larger trees and deep rooting drought tolerant species such as lucerne, grapes and olives have root systems that can penetrate to greater depths. A conservative estimate of rooting depth would lead to a similarly conservative estimate of the soils available water capacity which would limit the amount of water available for evapo-transpiration during periods of climate deficit. Given that close to 80 % of the catchment is vegetated in improved pasture, native grasses and tussock errors in the estimation of the rooting depth are expected to be minor.

Catchment evapo-transpiration was estimated by spatial averaging the fourteen point measurements using the Thiessen polygons method. The fourteen sites are biased towards lower elevations and valley floor positions. Higher elevations and hilltop situations generally experience higher precipitation, which would reduce the periods when actual evapo-transpiration is limited due to climatic deficits. Similarly hilltop situations generally experience less topographic shading and are often more exposed to wind than valley floors which would tend to increase potential evapo-transpiration rates. Conversely the lower temperature and increased frequency of cloud or rain tends to reduce potential evapo-transpiration rates at higher elevations.

Given the potential sources of error outlined above the error range for the estimate of catchment evapo-transpiration is expected to be ± 10 %. The 1951-2000 mean annual evapo-transpiration rate for the Waipara Catchment is estimated at 475 mm ± 10 %, or within the range 428 mm/yr to 523 mm/yr.

(b) River Flow

Utilising the Flow Model described in Chapter 4, the 1951-2000 mean annual flow in the Waipara River at White Gorge is some 3308 l/s. As shown in Figure 4.4, this represents a flow of 4720 l/s at the Teviotdale Recorder. Annually, some 149 million m^3 of water flows out of the catchment which equates to 212 mm per unit area of the catchment.

The accuracy of this estimate is dependant on three variables:

1. the flow data obtained from the White Gorge recorder,
2. the Flow Model used to extend the flow record, and
3. the extrapolation of flow in the Waipara River at White Gorge to flow out of the catchment at Teviotdale.

Environment Canterbury has operated the White Gorge recorder site since February 1988. The site has been operated in accordance with standard hydrological practices and data from the site has been audited against nationally accepted quality assurance standards (Lockington, 1992). Mean Annual Flow rates calculated for the site are expected to be very accurate (within 5 % of actual) given the quality of the data collected, the length of records (12 years) and the averaging effect which tends to attenuate errors in the instantaneous flow records.

The errors associated with the model were discussed in Chapter 4 and are expected to be relatively small with the standard error of the model being approximately 4% of the mean annual flow. The correlation factor between flows at White Gorge and those at the Teviotdale recorder is 95%. The data used in the correlation, represented both high and low flows and covered the range of mean annual flow. As such, errors associated with extrapolating the flow at White Gorge to flow at Teviotdale are expected to be minor.

Due to the above errors, the 1951-2001 Mean Annual Flow estimate for the Waipara River at Teviotdale is 4720 l/s ± 5%, or within the range 4480 l/s (202 mm/year) to 4960 l/s (223 mm/year).

6.2.5 Water Balance for the Waipara Catchment

The 1951-2000 mean annual water balance for the Waipara Catchment is:

$$P - E - Q_{out} - \Delta R = \Delta G$$

The water balance reveals a net groundwater movement ΔG of 85 mm/yr (Table 6-4). On an annual basis, net groundwater movement is out of the catchment at a rate of almost 60 million m^3 per year or 1.9 m^3/s. This is equivalent to approximately 40 % of the river flow out of the catchment. While the error range associated with this estimate is large, the estimate gives a direction and order of magnitude of net movement of groundwater in the Waipara Catchment.

Table 6-4 1951-2000 Mean Annual Water Balance calculation for the Waipara Catchment

Water Balance Variable		**1951-2000 Mean Annual Catchment Discharge** mm/year/unit area		
		Minimum	**Best Estimate**	**Maximum**
Precipitation	P	732	771	857
Actual Evapo-Transpiration	ET_A	428	475	523
River Outflow from the Catchment	Q_{out}	202	212	223
Net Import of Water into the Catchment	ΔR	-0.5	-0.5	-0.5
Net movement of Groundwater	**ΔG**	**-14**	**85**	**228**

Sensitivity analysis revealed that catchment precipitation and actual evapo-transpiration are the dominant values in the water balance. The accuracy of the water balance is therefore predominantly determined by errors in the estimates of catchment precipitation and actual evapo-transpiration (Table 6-5).

Table 6-5 Sensitivity Analysis of the 1951-2000 Mean Annual Water Balance for the Waipara Catchment.

Variable	**Value** mm/year	**Calculated net movement of Groundwater** mm/year	**Difference** mm/year	**Percentage Error** %
P min	732	46	-46	-54 %
P max	857	171	86	101 %
ET_A min	428	132	47	55 %
ET_A max	523	37	-48	-56 %
Q_{out} min	202	95	10	12 %
Q_{out} max	223	74	-11	-13 %
ΔR min	0.5	85	0	0 %
ΔR max	0.5	85	0	0 %
Best Estimate		**85**		

The water balance was undertaken on a sub-catchment basis to determine net groundwater movement for the major sub-catchments of the Waipara River. The upper catchment above White Gorge and the Weka Creek catchment loose small quantities of groundwater (41 mm/yr, and 35 mm/yr respectively), while, the Omihi Stream catchment looses a significant quantity of groundwater (187 mm/yr or approximately 1000 l/s) (Table 6-6). It is suspected that groundwater in the upper catchment flows in a northerly to north-easterly direction through the Mason Flat area following the dip of the tertiary rock units. This is consistent with the identification of flow losses from the upper Waipara River (Chapter 4.2.3). Groundwater from the catchments of Weka Creek and Omihi Stream is known to flow to the south through the gravels which underlie the Glasniven Flats (Loris, 2000).

Table 6-6 1951-2000 Mean Annual Water Balance calculation for the Waipara River Sub-catchments

Water Balance Variable	mm/yr	**1951-2000 Mean Annual Catchment Discharge** mm/yr			
		Upper catchment above White Gorge	**Weka Creek**	**Omihi Stream**	**Total**
Precipitation	P	838	693	772	771
Actual Evapo-Transpiration	ET_A	485	465	484	475
River Outflow from the Catchment	Q_{out}	312	194	103	212
Net Import of Water into the Catchment	ΔR	-	1.0	1.5	0.5
Net movement of Groundwater	**ΔG**	41	35	187	85

6.2.6 DISCUSSION OF THE WATER BALANCE

Using Darcys Law (Darcy, 1856) and the findings of Loris (2000), groundwater flow in the Canterbury Teviotdale Gravel Aquifers under the Glasnevin Flats was conservatively estimated at 200 l/s (refer Appendix 6.1 for the calculation). Flow is directed out of the Waipara Catchment towards Amberley. Comparison with the identified groundwater losses from the Weka Creek and Omihi Stream catchments suggest that the lower catchment is leaking groundwater in areas other than out through the gravel aquifers of the Lower Waipara Basin. This supports the suggestion that deeper groundwater exists within the lower Kowai or Tertiary beds.

Horrell (1992) identified the Masons Flat area as an area where surface water was being lost to groundwater and it is speculated that groundwater could be moving out of the Waipara Catchment to the catchments of both the Waitohi and Hurunui Rivers to the north. Unfortunately there is insufficient water level data from the Masons Flat area to determine a potentiometric gradient and groundwater flow direction. It is noted that while a number of wells have been drilled in the Masons Flat area, most have tended to be either dry or very low yielding suggesting there is limited groundwater in the area. The identification of groundwater losses from the upper catchment as indicated by the water balance, support the findings of Horrell (1992).

The presence within the catchment of significant areas of limestone sediments with karst topography and numerous sinkholes provides a potential pathway for water to leak from the catchment, particularly from the Coastal Hills where the limestone strata dips towards the catchment boundary. Numerous large springs emerge from areas of limestone and sandstone geology to the east of Mount Cass. During landowner interviews, a number of landowners stated that fresh water up-welling (potentially caused by large springs on the seabed) occur off the coastline east of Mount Cass. The gauging runs undertaken as part of this study identified surface water losses to groundwater in both the Weka Creek and the Main Waipara River over lengths where the substrate was limestone and sandstone. Similarly the only borehole (M34/5573) that penetrates into the limestone and sandstone beds, has the third highest yield of all boreholes in the Waipara Area. Finally, the very low runoff contribution of the upper Omihi Stream catchment (1.12 $l/s/km^2$) (Horrell, 1992) and the higher runoff contribution of the adjacent Motunau River catchment (2.57 $l/s/km^2$, Horrell 1992), suggest that groundwater could be moving from the Omihi Stream Catchment to that of the Motunau River. Although it is noted that the Motunau catchment itself has very low runoff suggesting losses to deep groundwater.

As outlined in Chapter 2, the Waipara area is tectonically very active and numerous folds and reverse/thrust faults cross the topographic boundary of the catchment. Movement of groundwater out of the catchment along fault traces, particularly fault traces through limestone sediments, is also possible.

6.3 RESOURCE SUMMARY FOR THE WAIPARA CATCHMENT

To summarise the information collected in this and previous chapters two, schematic diagrams have been produced which highlight the water resources for the Waipara Catchment during both the wetter winter months and the dry summer months (Figure 6.3 and 6.4).

The summer period covers the months of December to February while the winter period covers June to August. The diagrams highlight:

- mean monthly precipitation and actual evaporation at fourteen sites in the Waipara Area,
- mean monthly river flow at various sites within the catchment,
- mean monthly groundwater recharge rates,
- mean monthly allocated and actual water usage, and
- annual net groundwater movement out of the catchment.

The precipitation and actual evapo-transpiration rates were determined from monthly precipitation records and Thornthwaite soil water balances undertaken at each site (Chapter 3). Flow in the Waipara River was determined from the White Gorge flow recorder which has been operational since February 1988. Regression relationships based on instantaneous flow gauging data were used to determine flow at various other sections of the river (Chapter 4). Flow data and information from the Thornthwaite soil water balances was used to calculate groundwater recharge rates (Chapter 5). Net groundwater movement was calculated in the water balance presented at the start of this chapter. The volumes of water both allocated and actually used within the catchment were determined from analysis of Environment Canterbury's resource consent files and landowner interviews (Chapters 4 and 5).

The diagrams highlight the seasonal nature of the water resources of the Waipara Catchment. This is primarily due to the very seasonal effect of evapo-transpiration. During the winter months the mean annual outflow of the Waipara River is almost 8500 l/s; however this drops to slightly over 1350 l/s during the summer months.

Water allocation and use from Weka Creek, Home Creek and Omihi Stream is significantly higher during the winter months than the summer. This is mainly due to the Glenmark

Irrigation Scheme which harvesting water during higher flows. Water usage from the main Waipara River is almost 500 % greater in the summer than it is during winter. This highlights a potential problem in that greatest water usage from the Waipara River coincides with the period of least flow. There is potential to supplement some of the summer water takes from the main Waipara River by harvesting water during the winter months and the author is aware of at least two water users which are investigating this possibility.

Groundwater use is essentially restricted to the summer months with only minor domestic and stock water abstractions occurring over the winter. Groundwater recharge from the infiltration of precipitation is limited to the winter months with essentially no recharge occurring over the summer. Recharge from seepage from the area watercourses occurs throughout the year although the rate of recharge is reduced by approximately half during the summer. During the winter recharge from seepage represents approximately 10% of the recharge from the infiltration of precipitation.

Groundwater flows out of the catchment at a rate of 1900 l/s. This represents less than 25% of the river flow out of the catchment during the winter but is 40% larger than the summer out flow.

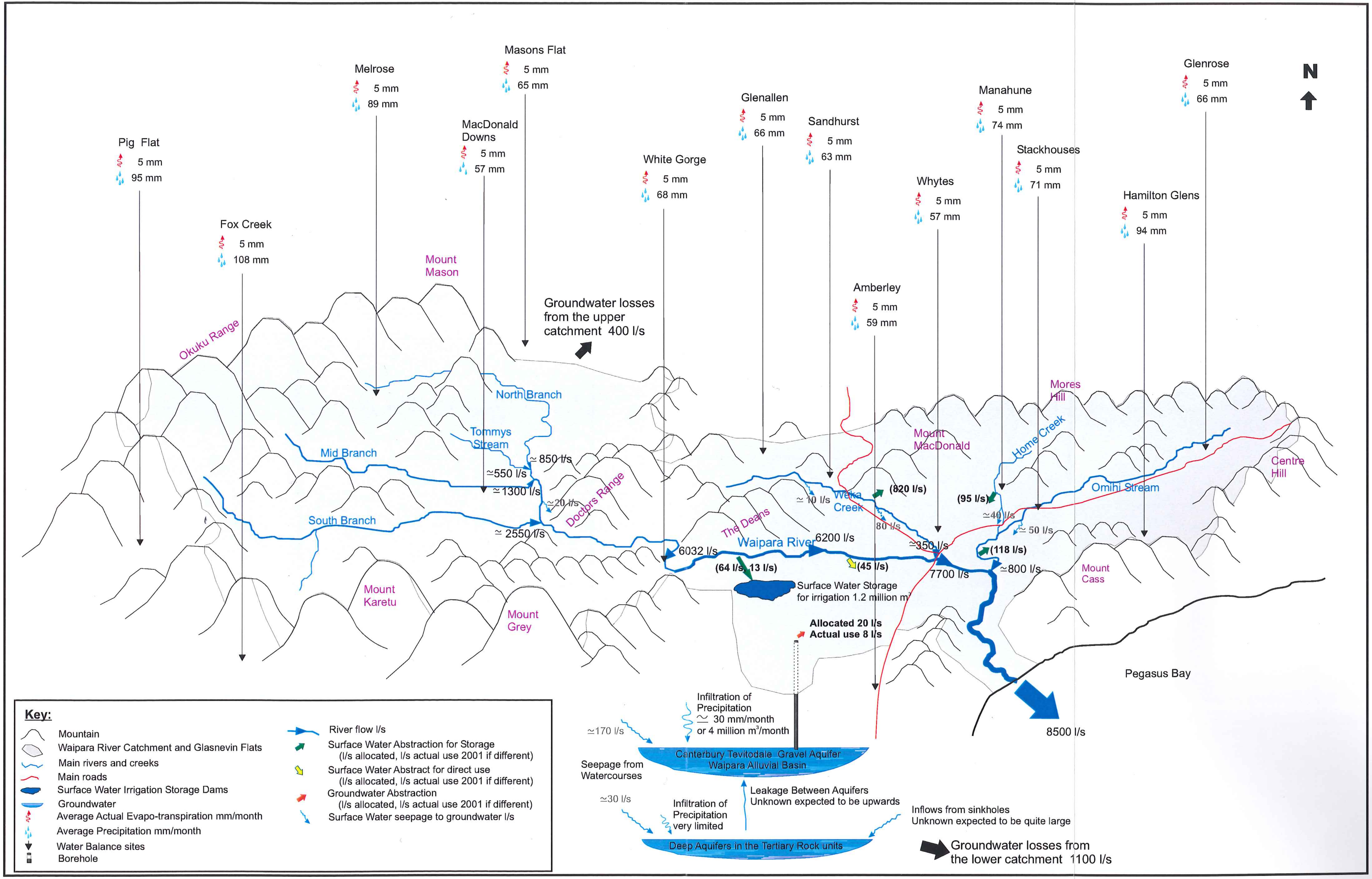


Figure 6.3 ***Schematic Diagram of the Water Resources of the Waipara Catchment during the winter (June – August)***

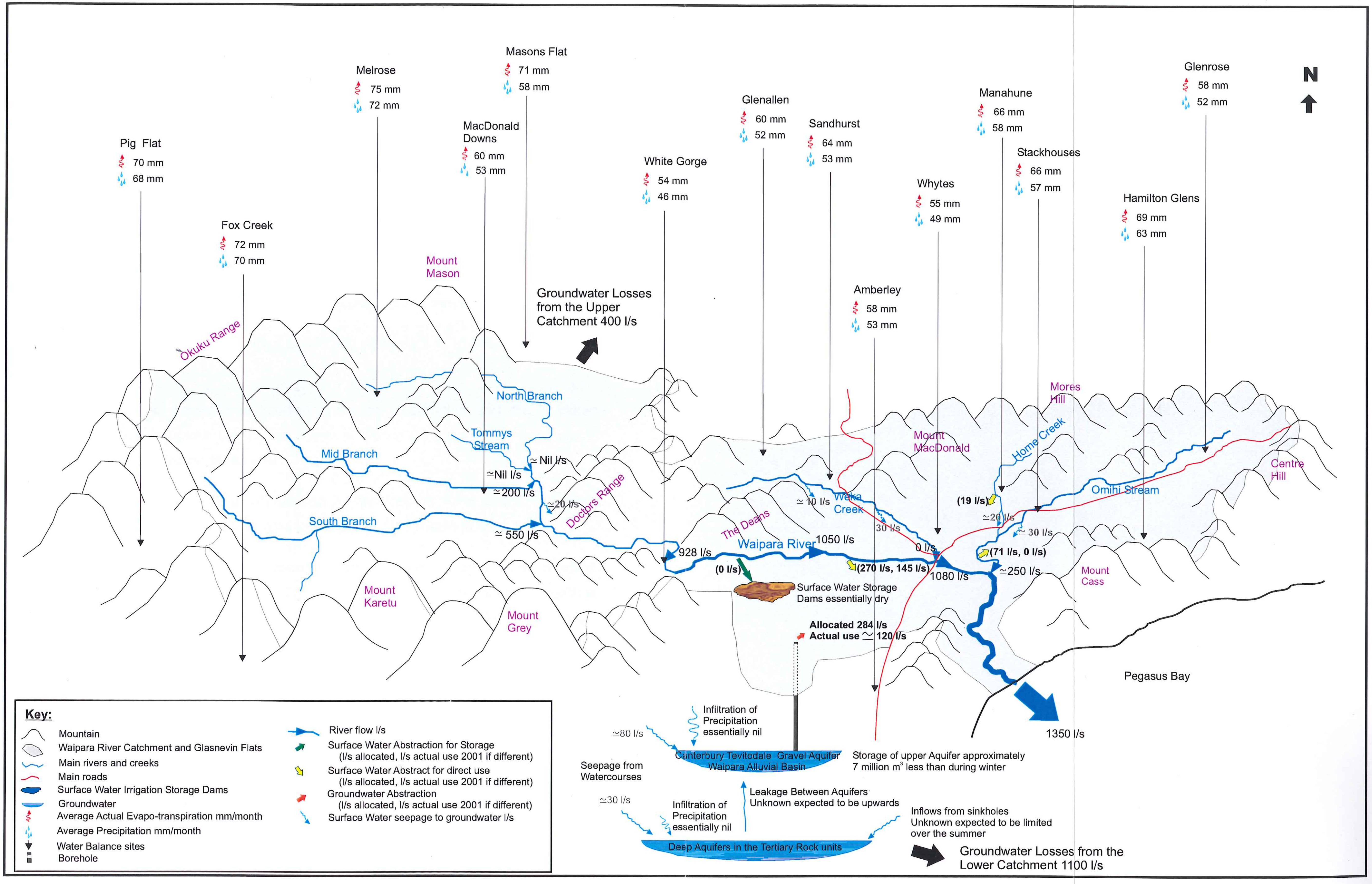


Figure 6.4 Schematic Diagram of the Water Resources of the Waipara Catchment during the Summer (December- February)

6.4 SUMMARY

A water balance using climate and surface water hydrology data from the previous chapters is established for the catchment to estimate net groundwater movement from the catchment. The key findings obtained from the water balance were:

- Using precipitation records from 14 sites the Thiessen polygons method indicated that the 1951-2000 mean annual precipitation for the Waipara Catchment was 771 mm/y (541 million m^3/yr) ± 5 %. The upper catchment receives 51% (838 mm/yr, 277 million m^3/yr), Omihi Stream and Home Creek 23 % (772 mm/yr, 122 million m^3/yr) and Weka Creek 11% (693 mm/yr, 61 million m^3/yr) of the precipitation.

- Using a precipitation map which accounts for elevation the 1951-2000 mean annual precipitation for the Waipara Catchment was calculated as 857 mm/yr (604 million m^3/yr).

- The rural water supply schemes import almost 900 m^3/day ± 5 % (0.5 mm/yr, 0.3 million m^3/yr) into the catchment.

- Based on soil water balances undertaken at the 14 precipitation sites the Thiessen polygons methods indicates that the mean annual 1951-2000 actual evapo-transpiration was 475 mm/yr (333 million m^3/yr) ± 10 %.

- The estimated 1951-2000 mean annual flow in the Waipara River at the Teviotdale recorder is 4720 l/s ± 5 %, which equates to 212 mm/yr (149 million m^3/yr) ± 5 %.

- For the Waipara catchment the net movement of groundwater is in an outwards direction at an estimated rate of 85 mm/yr (60 million m^3/yr, 1900 l/s). It is suspected that much of the ground water movement out of the catchment is via flow though the tertiary strata particularly in the Omihi Stream catchment.

- Net groundwater movement varies between the subcatchment of the Waipara River with the upper catchment above White Gorge loosing 41 mm/yr, Weka Creek 35 mm/yr and Omihi Stream 187 mm/yr.

An outline of the area's water resources under both summer and winter conditions was also developed which highlighted the following key points:

- The water resources of the Waipara catchment are extremely seasonal due to the effects of evapo-transpiration. During summer actual evapo-transpiration exceed precipitation.

- During the winter months (June –August) mean annual flow in the Waipara River at the Teviotdale Recorder is over 8500 l/s while over the summer months (December-February) this drops to slightly over 1350 l/s.

- Water abstractions from Home Creek, Weka Creek and Omihi Stream occur predominantly during the winter while water abstractions from the Waipara River are dominated by summer abstractions.

- There is potential for water harvesting of high flows in the Waipara River to augment water abstraction during summer low flows.

- Annual groundwater recharge to the Canterbury/Teviotdale gravel aquifers has been estimated at between 19 and 24 million m^3 and occurs predominantly during winter due to infiltration of precipitation (16-19 million m^3). Seepage from the areas watercourses is estimated to recharge the areas groundwater by between 3 and 5 million m^3 annually.

In describing the water resources of the catchment the first objective of this study has been achieved. The description is used to as a basis for making management recommendations in the following chapter.

SECTION THREE

WAIPARA WATER RESOURCE MANAGEMENT

7 WATER RESOURCE MANAGEMENT IN WAIPARA

7.1 INTRODUCTION

The aim of this chapter is to identify the issues facing the management of the water resources of the Waipara area and to use the information generated in previous chapters to make management recommendations. The issues facing water management are identified through stakeholder interviews, which are then discussed with consideration of the current management structure and the resource summary presented in Chapter 6. Management recommendations are presented at the end of the chapter.

As outlined earlier, the focus of this study is the quantity of the water resources of the Waipara catchment, their use and allocation. Water quality is not investigated and this chapter does not consider water management in regard to water quality.

7.2 PREVIOUS WORK

Finlayson and Brizga (2000) suggest that water management in New Zealand has evolved through three main phases: inception, engineering and environmental. The inception phase covered the efforts of individual settlers to obtain water supplies, drain swamps and control flooding and erosion. In Waipara, this phase was typified by the development of water schemes for individual properties including the digging of numerous shallow wells, the construction of windmills and the tapping of springs. The engineering phase was characterised by governments and statutory authorities taking a leading role in water management, and involved extensive engineering works and services. The development of both the rural water supply schemes and the Glenmark Irrigation scheme occurred during this phase. The environmental phase covers the recent shift to more holistic management. In New Zealand, the enactment of the Resource Management Act (RMA) in 1991 which promotes sustainable management of resources, is an example of this shift.

The value of holistic whole catchment studies to quantify the impacts of both natural and anthropogenic change on land and water resources is well recognised (Bowden, 1999; Thompson, 1999; Australian Representative Basins Program, 1982). New Zealand has a long history with whole catchment studies from the establishment of the 'Representative Basins Programme' between 1964 and 1976 (Toebes and Palmer, 1969; Toebes and Morrissey, 1970) through to a integrated catchment management study currently being undertaken on the Motueka Catchment near Nelson (Tasman District Council et al., 2002). The majority of these studies have focused on describing catchments and collecting hydrological information on the effects of both different land-uses and land-use change. Such studies have provided useful information for planning, resource management and environmental monitoring throughout New Zealand, but have generally not included the social aspects of catchment management. The Motueka study and similar New Zealand ones, for example the Taieri River Otago, the Whatawhata Catchment Hamilton and Waitakere Catchment near Auckland (Tasman District Council et al., 2002) as well as international projects such as the Hydrology for the Environment, Life and Policy (HELP) programme (UNESCO - United Nations Educational Scientific and Cultural Organisation, 2002), indicate a move towards integrated studies aimed at improving the link between knowledge of the physical environment and the needs of society.

Integrated (or total) catchment management is widely recognised as an appropriate means for achieving sustainable management of water resources (Mitchell, 1990; Bowden, 1999; Loucks et al., 1999; Brizga and Finlayson, 2000; Memon, 2000; New Zealand MfE, 2000). Bowden (1999) suggested that although the RMA is based on an integrated approach to environmental management, the practical application of the RMA to date has not generated this integration. Bowden suggested that due to limited resources, Regional and District Councils prioritised the production of policy and planning documents during the initial years of the RMA. Frieder (1997) noted that this planning, while valuable, left little time or effort for implementing integrated environmental management. The development of Catchment Management Plans via participatory approaches is seen by the author as a method for achieving this integration. Such plans provide physical hydrologists with the opportunity to consider communities and the greater environment as promoted by Young et al. (1994). Martin and Lockie (1993) highlighted the need for information to be generated in a form that allows a catchment wide perspective and encourages meaningful community participation, and that catchment management should be 'community driven' rather than 'expert centred'. This was further supported by Syme et al. (1994) who found that community ownership of the management process was vita to Australia's 'Whole Catchment Management Programme'.

Environment Canterbury and its predecessors have produced catchment plans under the Resource Management Act 1991 for the Waimakariri and Opihi Rivers (Canterbury Regional Council, 1995a, 1995b), and are currently developing a management plan for the Ashley River which is situated immediately south of the Waipara catchment (Mosley, 2001a, 2001b). The Resource Management Act 1991, ensures that water management in New Zealand involves extensive consultation with stakeholders (Court of Appeal, 1991; Environment Court New Zealand, 1998). As such, the production of the Waimakariri and Opihi Plans and the current process for the Ashley River have involved extensive consultation including the formation of stakeholder and user groups.

In regard to water management in the Waipara area, in 1993 the Canterbury Regional Council produced an issues and options document as the starting point for the development of a catchment management plan. The water resources of the area were summarised and five key water management issues were identified: (1) minimum flows, (2) water allocation, (3) the effects of land-use change, (4) resource usage information and (5) riverside willows. A change in planning focus from catchment plans to regional plans resulted in the Waipara Catchment Plan being put on hold while Environment Canterbury developed the Canterbury Natural Resources Regional Plan.

7.3 CURRENT WATER MANAGEMENT IN WAIPARA

The management of water resources throughout New Zealand falls under the legislative framework provided by the Resource Management Act 1991 (RMA). Within Canterbury the RMA requires that various policy documents and plans are produced (Figure 7.1).

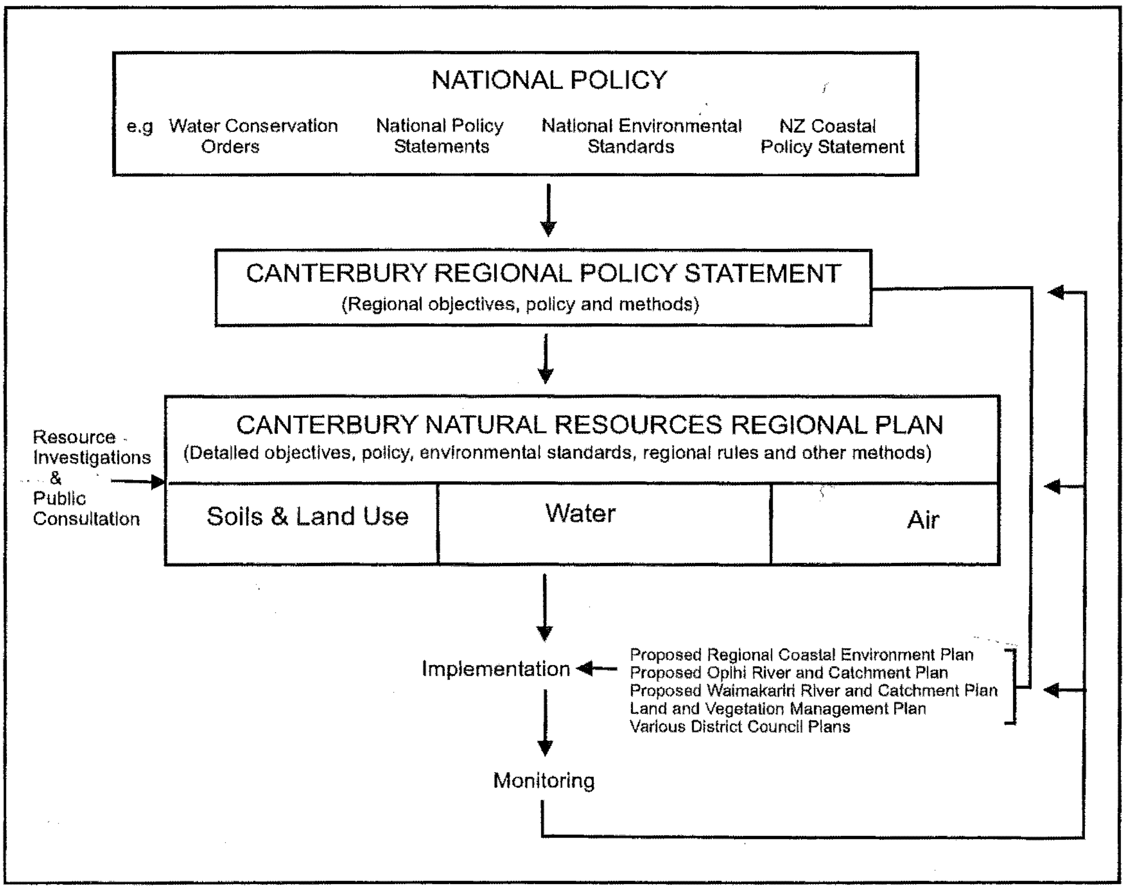


Figure 7.1 The Regional Planning Framework for Canterbury under the RMA

(Adapted from Canterbury Regional Council, 1999, p23)

The overall purpose of the RMA is *"to promote the sustainable management of natural and physical resources"* (Section 5, Part II, RMA 1991). Under Section 30 of the RMA, Environment Canterbury has been given the role to promote the sustainable management of Canterbury's water resources. In regard to water quantity, Environment Canterbury suggests that sustainable management will involve ensuring that *"changes to flows and water levels do not compromise ecological processes and the range of values and uses provided to present and future communities"* (Canterbury Regional Council, 1999, p15).

As required under the RMA, Environment Canterbury produced a Regional Policy Statement (Canterbury Regional Council, 1998) which sets out how natural and physical resources are to be managed in an integrated way to promote sustainable management throughout Canterbury. According to the Regional Policy Statement (RPS), it is a priority that a water level, flow and allocation regime be established for the Waipara and Kowai Rivers, their catchments and associated groundwater systems (Canterbury Regional Council, 1998, Policy 4, Chapter 9, p128-129).

7.3.1 REGIONAL PLANS

Environment Canterbury is currently reviewing their policies and procedures in relation to the management of the natural resources of Canterbury. During this review process, numerous policy documents have been produced and extensive consultation undertaken. In relation to water quantity and management, '*Water our Future*' (Canterbury Regional Council, 1999) was produced as a starting point for the process and the recently produced draft chapters of the '*Canterbury Natural Regional Resources Plan*' (NRRP) (Environment Canterbury, 2001) summarise Environment Canterbury's current position.

The draft NRRP addressed the issue of water quantity by initially establishing procedures for setting flow and/or water level regimes and then outlining how water will be allocated. Flow regimes should determine minimum flows and may include additional provisions such as sharing, or a cap on abstractions to maintain flow variability. The draft NRRP indicates that in establishing a flow and water level regime for the Waipara Catchment, particular regard should be had for the *'mauri'* (life force) of the river and the habitat of native fish (Environment Canterbury, 2001, Policy WQN4, p5-35). The total amount of groundwater allocated for abstraction in the Waipara area is to be restricted so that there is no significant long-term decline in mean annual groundwater levels (Environment Canterbury, 2001, Policy WQN 10, p5-47).

Environment Canterbury's objective in relation to water allocation is to

(a) *"maximise the amount of water that is available for allocation, and allocate it in ways that enables people and communities to maximise their social, economic an cultural well being and their health and safety.*

(b) *establish allocation regimes that identify at least a primary allocation block within which the reliability of supply does not become a factor that limits the long-term economic viability of uses that are dependent on water."*

(Environment Canterbury, 2001, Objective WQN 3, p5-49).

Security of water supply is the main consideration when determining the size of the primary allocation block. For surface water abstractions, an appropriate level of security has been defined as having a high level of water availability for three out of five years with a severe event occurring one year in ten. For groundwater abstractions, a high level of availability is to be achieved four years out of five with a severe event occurring one year in twenty. Once a flow and water level regime is operative for the Waipara catchment, a water allocation regime is to be developed which will determine the maximum volumes and/or rates of water that can be abstracted. If the existing amount of water already allocated exceeds the allocation regime, Environment Canterbury plans to review the reasonable use needs of each water user. The draft NRRP requires that abstractions be metered, and that water be used in an efficient manner and wastage avoided. The NRRP also provides guidance on how bores should be established and how groundwater abstractions shall be managed in terms of interference effects on neighbouring wells and stream depletion.

The Waipara Catchment has no allocation regime and the draft NRRP indicates that as an interim measure, the maximum surface water allocation will be; the flow exceeded 80% of the time during January and February less the established minimum flow. Similarly for groundwater, the maximum allocation will be 50% of the annual recharge. Using flow data from White Gorge, the surface water allocation limit would be 26 l/s (80% exceedence flow for January and February of 76 l/s less the minimum flow of 50 l/s). It is noted that 270 l/s are currently allocated from the Waipara river during summer (Chapter 4.2.8), indicating that the river is currently well over allocated when compared to the guidelines outlined in the draft NRRP. Recharge to the gravel aquifers of the Waipara Alluvial basin from the infiltration of precipitation (16-19 million m^3) and seepage from watercourses (3 – 5 million m^3), has been estimated at between 19 and 24 million m^3. It is estimated that a minimum of 6 million m^3 of this recharge is required to cover normal summer decline in the unconfined aquifers. This leaves a maximum of between 13 and 18 million m^3 which could potentially be available for abstraction. Currently 18,013 m^3/day is allocated via resource consents (Chapter 5.3.4), most of which is for summer irrigation. Assuming irrigation continues for a maximum of 6 months, the current allocations equates to between 18% (18 million m^3 recharge) and 25% (13 million m^3 recharge) of the estimated maximum recharge. While this suggests the potential for further allocation, it is noted that recharge is not evenly distributed throughout the Waipara Alluvial Basin and many of the existing abstractions are in areas where recharge is expected to be very limited (the shallow confined aquifers under the Glasnevin Flats and the eastern portion of Omihi Valley).

In regard to the impact of land-use change on water yield, the draft NRRP is principally concerned with the impacts of afforestation of pasture catchments. Afforestation can cause a significant reduction in water yield and catchment runoff (Dons, 1987; Fahey and Watson, 1991). The draft NRRP addresses this issue by identifying *'forestry sensitive catchments'* and proposing controls on the afforestation of these catchments. Waipara due to its low elevation, low rainfall and lack of storage is classified as a forest sensitive catchment, and therefore could face future controls on afforestation.

7.3.2 CONSENTS

As the NRRP is not currently operative, management of the water resources of the Waipara area is based around controlling water abstractions via resource consents. Six minimum flow sites have been established in the Waipara catchment (Table 7.1).

Table 7.1 Minimum Flows in the Waipara Catchment

River or Stream Reach	Minimum Flow (l/s)	Gauging Site	Year Created
Waipara River above Stringers Bridge	50	White Gorge	1994
Waipara River between SH1 and Stringers Bridge	60	Stringers Bridge	1978
Waipara River below the SH1 bridge	80	Greenwoods (Teviotdale) Bridge	1978
Omihi Stream	57	Baxters Road Bridge	1977
Home Creek	57 10	Kings Road Bridge Kings Road Bridge	1977 1987
Weka Creek	28	Below the Glenmark Irrigation Scheme intake structure	1977

Most of the minimum flows were determined in the absence of any quantitative data and there are a number of inconsistencies in the minimum flow regimes. Questions have been raised over the ability of the minimum flows to protect the aquatic ecosystems of the Waipara River (Canterbury Regional Council 1993).

The lack of continuous flow data from all but the White Gorge site, makes it difficult to implement the minimum flows. Flows at both Stringers Bridge and Greenwoods (Teviotdale) Bridge can be accurately estimated from the flow at White Gorge (Table 4.1 Chapter 4), but flow at the other three sites (Baxters Bridge, Kings Road Bridge and below the intake for the Glenmark Irrigation Scheme) must be measured using instantaneous flow gauging. It is noted that the January 2001 and April 2001 gauging runs undertaken as part of this study indicated that flow in both Omihi Stream and Home Creek were below the minimum flows; however Environment Canterbury did not impose minimum flow restrictions on either watercourse during the 2000-2001 summer.

Of the 29 existing consents that authorise the abstraction of either surface water or hydraulically connected groundwater, 26 have conditions relating to minimum flows or residual flows (Table 7.2). There are a number of inconsistencies in the minimum flow conditions with different minimum flows applied to similar activities. Most (19 of 26) of the minimum flow conditions relate to minimum flow sites which are upstream of the abstraction points and their effectiveness is questioned. Under the current regime (when the flow in the Waipara River at White Gorge is immediately above 50 l/s), the downstream users are authorised to abstract 184 l/s or three times the actual water available.

Table 7.2 Low Flow Conditions on current Water Permits in the Waipara Catchment as at 1 June 2001
(Summarised from Environment Canterbury's consent files)

Permit Holder	Consent Number	Minimum Flow or Residual Flow l/s	Minimum Flow Site
Home Creek			
Glenmark Homestead	CRC011833	10	Kings Road Bridge
Gould D.C.	CRC920808B	57	Kings Road Bridge
Hutt Creek Vineyards Ltd	CRC920812B	57	Kings Road Bridge
McGuckin D.J.	CRC920820	10	Kings Road Bridge
Omihi Stream			
Corbins Wines Ltd	CRC920816A	57	Baxters Road Bridge
Glenray Farming & Chancellor	CRC920817B	57	Baxters Road Bridge
Stackhouse K.W.	CRC920814B	57	Baxters Road Bridge
Stackhouse K.W.	NCY800639	57	Baxters Road Bridge
East M.C. (tributary)	CRC920699A-B	1.0 Residual flow	Small Tributary
Savill E.M. (tributary)	CRC916346A-B	0.5 Residual flow	Small Tributary
Weka Creek			
Whyte A.E. and others	CRC920803C	28 Residual flow	
Waipara River			
Canterbury House Vineyard	CRC940238	50	White Gorge
Johns B.S.	CRC940475	50 and 53	White Gorge
Litchfield Nominees No 14 Ltd	CRC010463	65	White Gorge
Maungatahi Farms	CRC950255	161	White Gorge
Stewart R.G.	CRC992263	50	White Gorge
Tutton, Sienko & Hill	CRC920498	50	White Gorge
Williams G.E.D.	CRC920790	600	White Gorge
Chapman B.A.	CRC000546	60	Stringers Bridge
Maungatahi Farms	CRC920587	60	Stringers Bridge
Maungatahi Farms	NCY840049	60	Stringers Bridge
Rangatahi Downs Ltd	CRC920588	60	Stringers Bridge
Retallick T.E. & M.C.L.	CRC920650	60	Stringers Bridge
Croft W.H. & R	CRC920476	80	Teviotdale (Greenwoods) Bridge
Donaldson I.M & C.C	CRC920345A	80	Teviotdale (Greenwoods) Bridge
Donaldson I.M & C.C	CRC920345B	80	Teviotdale (Greenwoods) Bridge

Environment Canterbury has established procedures for considering consent applications whereby the proposed activity is assessed against the requirements of the RMA, the associated plans and relevant council policies. The surface water resources of the catchment are already highly allocated and it is recognised that potential abstraction rates exceed normal summer supply (RMA W100/95, 1995). It is noted that the last new surface water abstraction consent granted (excluding renewals) by Environment Canterbury was applied for in 1995 and involved a hearing of the Environment Court.

Environment Canterbury has recently received a large increase in consent applications for the abstraction of groundwater from the Waipara Alluvial Basin. Of the 24 current groundwater abstraction consents in the Waipara area, 13 were issued since the start of 1999. In assessing groundwater abstractions, Environment Canterbury considers the induced drawdown effects the abstraction may have on surrounding wells and boreholes and potential stream depletion effects. The complicated nature of the aquifers of the Waipara area (Loris, 2000), results in difficulties in assessing both induced drawdowns and stream depletion. In granting groundwater abstraction consents in Waipara, Environment Canterbury's current practice is to use a consent duration of 35 years (the maximum allowable under the RMA).

7.3.3 MONITORING

In relation to water quantity, Environment Canterbury's current monitoring programmes are separated into three sections:

1. Groundwater level monitoring,
2. Surface water flow monitoring, and
3. Compliance monitoring of water permits.

Historic groundwater monitoring in the Waipara area has been erratic and very limited. Seven wells and boreholes within the field area were measured between 1956 and 1986 by the North Canterbury Catchment Board and the Department of Scientific and Industrial Research as part of a three-monthly water level monitoring run. One well in the Waipara Township has 30 years worth of data and four others in excess of 20 years. The wells with long water level records are all relatively shallow (<20m), essentially tapping the unconfined aquifer, and there are no long term records of water levels in the deeper semi-confined and confined aquifers. Unfortunately the monitoring run was discontinued in 1986 and there is a gap in monitoring until late 1999 when Loris (2000) established a water level monitoring run for the Waipara Alluvial Basin. Currently Environment Canterbury monitors (on a monthly basis) the water level in 29 wells and boreholes in the Waipara Alluvial Basin. Continuous water level monitoring undertaken as part of this study has revealed that many of the 29 wells and boreholes are strongly affected by pumping which reduces the usefulness of the monthly point measurements.

Monitoring of surface water flows in the Waipara catchment is based around two continuous flow recorder sites (White Gorge and Teviotdale) and numerous instantaneous flow measurements. The current monitoring programme involves undertaking regular instantaneous flow gauging to continually update the flow rating curves for both sites and to undertake gauging runs down the river during periods of low flow. Detailed gauging runs undertaken as part of this study have assisted in determining tributary contributions and the interaction of surface water with groundwater.

Environment Canterbury have a programme of compliance monitoring whereby water permit holders are visited to check if they are complying with the conditions of their water permits. This usually involves using a flow meter to determine rates of abstraction and flow gauging to determine if minimum flows have been reached. In the Waipara Area a number of the consent holders have been visited, although to date the focus has been on discharge consents rather than abstraction consents. Environment Canterbury has used compliance monitoring to determine actual water usage in various parts of Canterbury. Until this study there was no information on actual water usage in the Waipara area.

7.4 CURRENT MANAGEMENT ISSUES

The issues associated with water management in the Waipara area were identified by researching the policies and positions of the following stakeholders that have an interest in the management of the water resources of the Waipara Catchment:

- landowners,
- tangata whenua namely Ngāi Tūahurirri Rūnanga of Ngāi Tahu,
- the Department of Conservation
- the Royal Forest and Bird Society
- the Fish and Game Council
- the Hurunui District Council, and
- Environment Canterbury

Policy documents and reports produced by the stakeholders were reviewed along with any submissions made in relation to water abstraction consents for the Waipara area. Interviews were held with representatives of the various stakeholder groups to assess the current issues. To allow comparison between stakeholders, a standard interview format was utilised (Appendix 7.1). The interviews took approximately an hour to complete and involved substantial discussion on the water resources of the area and their management.

7.4.1 LANDOWNERS

Water management in the Waipara area is a long standing and significant issue for all Waipara landowners. The lack of secure stock and domestic water sources was recognised as early as the 1960s when the landowners began the establishment of the various water supply schemes that now cover the area. The recent formation of the 'Water for Waipara' action group (August 1998) and the Omihi Irrigation Society (October 1999), indicates the current high level of interest in water management.

Interviews were held with 106 landowners from the Waipara area to assess their thoughts on the current use and management of water resources and their desires for the future. Collectively the interviewees own or manage over 570 km^2 (77% of the catchment), over 327000 stock units and represent 211 households. The majority of the interviewees are sheep and beef farmers indicating the major land-use in the area Table 7.3.

Table 7.3 Classification of Landowner Interviewees

Landowner Type (based on main economic activity *)	**Number**	**Percentage of Total**
Sheep, Beef and/or dryland Crop Farming	72.5	68
Viticulture	9.5	9
Irrigation Farmers (Excluding vineyards)	8	8
Other dryland Livestock Farming (Deer)	3.5	3
Lifestyle properties – with Grapes	4	4
Lifestyle properties – with Olives	4	4
Other Lifestyle properties	3.5	3
Forestry	1	1
Total	**106**	**100**

* Where a landowner is involved in 2 approximately equal economic activities they are assigned 0.5 each.

The interviewees showed a good understanding of the RMA with 44% having a fair to good understanding. Participation in the resource consent process was the main avenue for learning about the RMA. When asked to describe sustainable management in regard to water resources, 71% of the respondents gave a definition that was generally consistent with the principles of the RMA. The following quotes where given by the respondents:

- *"future users safe-guarded"* Interview No 8, 6/3/01
- *"not mining or over-using"* 24, 13/3/01
- *"appropriate and efficient use of water"* 9, 9/3/01
- *"maintaining water quality and not polluting"* 3, 2/3/01
- *"minimum flow levels"* 26, 15/3/01
- *"water security"* 31, 16/3/01
- *"conservation of the environment"* 47, 5/4/01
- *"monitoring, research and understanding"* 48,9/4/01
- *"maintaining fishery"* 63, 1/5/01
- *"not depleting springs"* 64, 1/5/01
- *"not upsetting natures balance"* 21, 12/3/01
- *"working with the environment"* 11, 7/3/01
- *"water is precious"* 69, 1/5/01
- *"biodiversity, big picture"* 69, 1/5/01
- *"need to plan long term"* Interview 78, 24/7/01
- *"minimise effects"* 98, 10/10/01.

In regard to whether or not Waipara's water resources are currently being managed sustainably: 41 respondents thought that they were, 17 thought they were not, with the remaining 45 having some concerns over current management, while 3 did not feel in a position to comment. The lack of understanding of the water resources (particularly groundwater), the lack of a management plan, the inefficient use of water by some landowners and the lack of flow in the Waipara River were the main reasons why the sustainability of the current management regime was questioned.

All the interviewees expressed a significant knowledge of current water use and management in Waipara. Concerns over the current management system could be grouped into the following eight main themes (in no particular order):

- security of domestic and stock water supplies,
- understanding of the water resources/environment,
- water quality,
- security of irrigation supply,
- environmental and ecological concerns over river flow,
- safe guarding future options,
- efficient use of water, and
- consultation and local involvement in management.

In regard to future management, the respondents outlined a number of issues as summarised in Table 7.4. A large number of landowners indicated that they were concerned with the lack of local input into current water management in Waipara, especially resource consents. It was suggested that resource consent applications should be presented to a committee of elected local landowners who would then make recommendations to the governing body. This is similar to the current system by which the various rural water supply schemes are managed.

Numerous landowners in the catchment have made submissions on resource consent applications to abstract surface water. Most of these submissions have been based on ensuring adequate water remains in the river for existing abstractors and encouraging the efficient use of water. Due to the already high level of allocation (particularly during the summer), existing abstractors are very concerned about applications for new abstractions.

Table 7.4 Water management issues as identified by Landowners

Issue	Number of Interviewees	Comments
Water management to be based on knowledge and information of the Waipara's water resources.	32	Need for more monitoring and research.
Local representation in water management, user groups to manage water under a set of rules.	29	The formation of the Water for Waipara group and the Omihi Irrigation Society.
An independent governing body is required to establish rules, ensure fairness and to protect the environment	28	Environment Canterbury was considered an appropriate governing body.
Use of water harvesting as an appropriate method for sustainably managing water.	21	The Glenmark Irrigation Scheme was considered a good example.
The need to put the limited water resources of the Waipara to the best possible use.	19	Assessment of actual water needs, use of efficient irrigation methods and drought tolerant crops.
Water allocation must be based on a fair and equal system.	19	There was a concern that existing users have tied up the water resources restricting future users.
The Waipara environment is precious, we need to work with it and protect it.	13	Rules are required to protect the environment, namely minimum flows in the Waipara river.
Numerous landowners rely on the rural water supply schemes.	11	The need to manage and maintain the rural water supply schemes.
The sharing of information and open consultation is vital to achieving good water management.	9	Any Catchment Management Plan must be developed through consultation.
Land development (e.g. establishing grapes) is a long-term venture and requires long term direction.	6	Development of a holistic long-term management plan.
Given the significant cost associated with establishing irrigation schemes developers need security of supply to justify investment.	5	Development of a flow regime which provides security of supply for irrigators.

To assess proposed development in the area and future land-use/water demand, interviewees were asked how they envisaged their property in 25 years. Based on landowner responses, a predicted land-use map was developed for 2025 (Figure 7.2). The significant land-use changes that have occurred in the catchment over the last 25 years (Table 2.1, Chapter 2) are projected to increase over the next 25 years (Table 7.5). Afforestation of over 5000 ha of predominately scrub and tussock land in the upper catchment is expected to occur. Landowners indicated that provided water was available they expected an approximately seven-fold increase in the area irrigated (an additional 6900 ha) for olives, vineyards and crops, with the area in vineyards conservatively expected to triple (an additional 750 ha) by 2025. Assuming an irrigation rate of 10 m^3 per ha per day (interviews with various olive and grape growers in the area) approximately 800 l/s of irrigation water would be required over the summer months to irrigate the 6900 ha for grape or olive production.

Table 7.5 Land Usage within the Waipara River Catchment and Glasnevin Flats 2001 2025 comparison

Land-use	**2001**		**2025**		**Change**	
	ha	**%**	**ha**	**%**	**Ha**	**%**
Urban Spaces	93	0.1	93	0.1	0	0.0
Bare Ground (River Bed)	327	0.4	327	0.4	0	0.0
Mine Dumps	9	0.0	9	0.0	0	0.0
Inland Water (Dams and Lakes)	19	0.0	19	0.0	0	0.0
Wetlands	10	0.0	10	0.0	0	0.0
Coastal Sands	29	0.0	29	0.0	0	0.0
Willows	556	0.8	533	0.7	-23	-0.1
Olive Groves	107	0.1	145	0.2	38	0.1
Vineyards	342	0.5	1097	1.5	755	1.0
Irrigated other (crops, pasture etc)	739	1.0	6788	9.2	6049	8.2
Prime Pasture	40001	54.1	31424	42.5	-8577	-11.6
Tussock and Native Pasture	16609	22.4	14208	19.2	-2401	-3.2
Scrub	7723	10.4	6825	9.2	-898	-1.2
Indigenous Forest	1079	1.5	1079	1.5	0	0.0
Planted Forest	6353	8.6	11410	15.4	5057	6.8
Lifestyle Blocks*	1377	1.9	2035*	2.8	658	0.9
Total (excluding Lifestyle Blocks)	**73996**	**100.0**	**73996**	100.0	0	0.0

* exclude from total as lifestyle blocks are already classified according to their land-use

Given that groundwater recharge rates are very low and the surface water resources are already well over allocated during summer (Section 7.2.1), substantial water harvesting of high flows and improved efficiency of water use will be required to achieve the projected increase in area irrigated. The author is aware of two landowners who are currently investigating the development of on-farm storage facilities to augment their abstractions during periods of low flow. Previous work indicates that the projected afforestation will reduce runoff, further limiting the flows in the Waipara River.

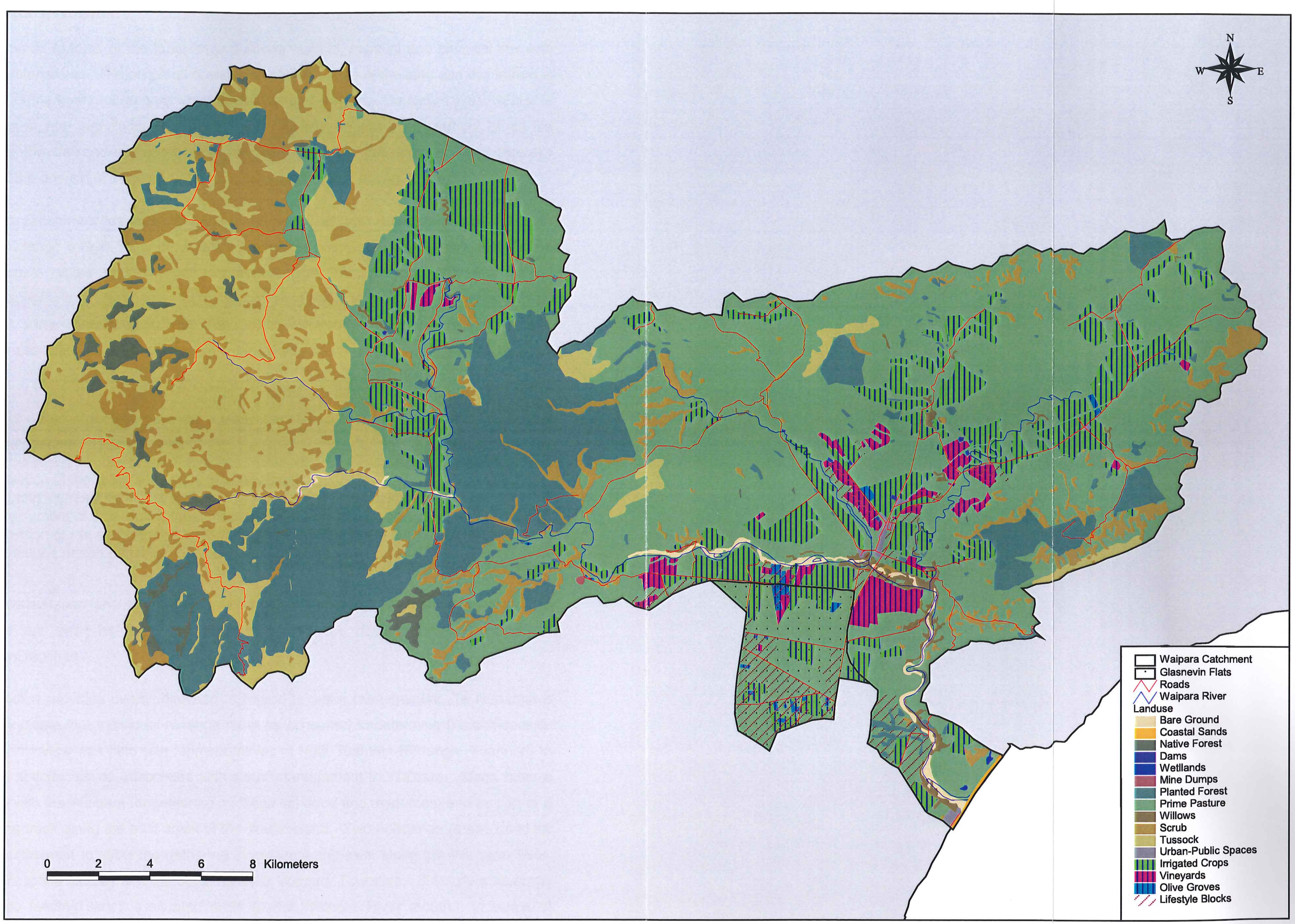


Figure 7.2 2025 Land-use Map for the Waipara Catchment

7.4.2 TANGATA WHENUA

Tangata whenua (people of the land) have a strong cultural, spiritual and physical link with water and waterbodies. The condition of water reflects the state of the land and this in turn is a reflection of the health of tangata whenua (Canterbury Regional Council, 1998). Water is identified as a very significant taonga (treasure) and is an essential element of all life representing the lifeblood of Papatuanuku (the earth mother), the tears of Rangi (the sky father), and the domain of Tangaroa (the guardian of the sea) (Larking, in press).

The Waipara Catchment lies within the rohe of the Ngāi Tūahurirri Rūnanga of Ngāi Tahu. In 1999, Te Rūnanga o Ngāi Tahu produced a freshwater policy statement which outlines the iwi's position in regard to freshwater resources. Ngāi Tahu strongly promotes holistic catchment specific strategies under their *'Mountains to the Sea'* policy (Te Runanga o Ngai Tahu, 1999, p11). According to Ngāi Tahu, each waterbody has its own natural/cultural values and associated issues which they suggest are best dealt with on a case by case basis.

In managing water, Ngāi Tahu are particularly concerned that the mauri (life force) of a waterbody is protected. This requires:

- Protection of the water's capacity to renew itself
- Ensuring instream flows are sufficient to sustain mahinga kai species
- Development of flow regimes that incorporate both minimum flows and flow variability
- Protection of the exchange of freshwater and seawater at the river mouth
- Prevent the unnatural mixing of waters from different water bodies

(Te Runanga o Ngai Tahu, 1999)

Thorough consultation and the collection and dissemination of information on individual waterbodies are seen as important requirements for the development of appropriate management regimes.

While the policy provides overall direction in regard to water management, Te Rūnanga o Ngāi Tahu indicate that individual rūnanga must be consulted to determine the site-specific issues. An interview was held with representatives of Ngāi Tūahuriri Rūnanga (Tūahuriri) to discuss the specific issues associated with water management in Waipara. Maori have a long history with the Waipara for gathering mahinga kai (food and resources) and as part of a main walking track along the east coast of the south island. Two nohoanga (areas used for temporary settlement to allow the gathering of mahinga kai) exist along the Waipara River, one adjacent to the estuary and the other near the Waipara Township. Similarly a tauranga waka (canoe landing sites) is situated north of the Waipara River mouth. In terms of instream values, the estuary, the upper Waipara River above Laidmore Road and the swamps in the upper catchment are considered the most important areas by Tūahuriri.

Tūahuriri are currently very concerned with the state of the Waipara environment. The occurrence of very low flows, the clogging of waterways by willows, the presence of significant algal growths during the summer and the reduction of mahinga kai, are seen as indications that the current management regime is not adequately protecting the environment and therefore can not be sustainable. Tūahuriri support the need for 'hands on' planning and management where management bodies actually visit areas, understand them and do actual work. The replacement of local water boards and catchment boards by regional councils and the centralisation of functions to Christchurch has in Tūahuriri's opinion resulted in a decrease in 'hands on' water management in the Waipara area. The increase in willows along the Waipara River over the last 10 years is cited as an example of the negative effects of this.

Tūahuriri believe that the water resources of the area are not well understood. There is a need for the development of a holistic management plan that establishes rules that can be enforced and monitored. They believe that such a plan needs to be based on a thorough understanding of the Waipara environment and produced via an open and fair consultation process. The current system of managing Waipara's water resources via resource consents is not supported by Tūahuriri, as it leads to repetition of the same issues and makes it difficult to consider the environment holistically. It is noted that to date Tūahuriri have not submitted on any consent applications involving water abstractions from within the Waipara catchment.

Tūahuriri highlighted the need for people who are involved in consultation to *buy into the process*. It was felt that some consultation processes were better described by the old adage of; *'we know you can hear us but are you listening'.*

In association with Environment Canterbury, Tūahuriri recently undertook a joint monitoring programme on the Waipara River aimed at establishing a relationship between Maori values for water and river flow (Larking, in press). The study was based on earlier work by Tipa and New Zealand MfE (1999), who undertook a similar study on the Taieri River, Otago. Three sites along the river were inspected and assessed by representatives of Tūahuriri on a monthly basis between September 1999 and October 2000. During the study, Tūahuriri assessed the overall health of the Waipara River to be good. While it was found that the mauri of the Waipara river was strongly linked to flow, the assessment of mauri required a holistic assessment of the river and the surrounding environment.

7.4.3 DEPARTMENT OF CONSERVATION

The Department of Conservation (Te Papa Atawhai) is a government organisation established by the 1987 Conservation Act with the mandate to conserve the natural and historic heritage of New Zealand. In relation to water management, the Conservation Act requires the Department of Conservation (DOC) to preserve indigenous freshwater fisheries and to protect recreational freshwater fisheries and fish habitats, much of which is achieved through conservation advocacy and via planning opportunities created by the RMA. Under the RMA, DOC has had significant input into the development of *'Flow guidelines for instream values'* (New Zealand Ministry for the Environment, 1998), *'Water our Future'* (Canterbury Regional Council, 1999) and the draft *'NRRP'* (Environment Canterbury, 2001).

For conservation purposes, DOC administers 146 ha of reserve land in the Waipara catchment (< 0.2 % of the catchment area). Similarly DOC considers the mouth of the Waipara River an important habitat for birdlife (O'Donnell and Moore, 1983).

DOC has not submitted on any water abstraction consents that have been granted in the Waipara Area and during an interview with DOC representatives, it was indicated that DOC does not have many concerns regarding the Waipara river and is more concerned with both the Hurunui and the Ashley rivers. DOC is currently promoting the protection of wetlands throughout the country and as such would like to see the wetlands in the Waipara catchment (particularly those in the upper catchment) protected.

DOC was recently involved in a stakeholder process to develop a flow regime for the Ashley River. The process was found to be very useful and DOC supports the use of stakeholder groups in the development of catchment specific management plans. During the Ashley River process, DOC sought a flow regime consisting of a minimum flow based on the 7-day mean annual low flow, and flow sharing above that.

DOC recognises and is concerned about the effects afforestation can have on water yield. Although in regard to forestry in the Waipara catchment, DOC is currently more concerned with the protection of native vegetation and the effects of forestry on habitat, landscape and visual values. In its submission on the proposed Hurunui District Plan, DOC sought controls on afforestation and that land-use consents covering forestry be assessed in terms of "*providing for the potential adverse effects of forestry on water yield*" (Todd, 2000, p5).

7.4.4 FOREST AND BIRD

The Royal Forest and Bird Protection Society is New Zealand's largest national conservation organisation and is active on a wide range of conservation and environmental issues. The Society's mission is to preserve and protect the native plants, animals and natural features of New Zealand.

While Forest and Bird have not submitted on any water abstraction consents in the Waipara Area, they consider the river to be over allocated and that ecological values are not sufficiently protected. The current practice of managing Waipara's water resources via resource consents and minimum flows is not supported, as successive applications to abstract water from the river can result in river flows being whittled away to nothing. Forest and Bird expressed concern over Environment Canterbury's current practice of issuing maximum duration (35 year) groundwater abstraction consents, as it does not believe there is sufficient understanding of the groundwater resources to do so.

In relation to water management, Forest and Bird support an ecological or ecosystem approach where all factors affecting water are considered. It suggested that while there is generally enough hydrological data, there is a lack of ecological information, which leads to ecosystems not being appropriately considered by decision-makers. Forest and Bird is concerned with ongoing land development (particularly viticulture and olives) in Waipara, as it will put even more pressure on the already stretched water resources of the area. The need to consider land-use and water use simultaneously was emphasised, and Forest and Bird consider it inappropriate to promote new land development when the water required for such development is not available.

Forest and Bird strongly support the RMA and the legislative framework it has established and believe it has enhanced New Zealand's environment. While Forest and Bird acknowledge that there are some problems with the RMA, it suggests that the majority of these are associated with implementation rather than the legislation.

7.4.5 FISH AND GAME

Fish and Game New Zealand is a crown entity established under the Conservation Act 1987 to manage, maintain and enhance freshwater sport fishing and gamebird hunting in New Zealand. Fish and Game is actively involved in habitat protection work, much of which is achieved through planning, advocacy and legal opportunities created by the RMA.

Overall, the Waipara River is not considered a significant sport fishery due predominantly to the low flows which occur during the summer months. A fisheries assessment of the river indicated that low numbers of Brown Trout *(Salmo trutta)* were only found in the mid to upper reaches of the Waipara River (Richardson, 1994). Landowner interviews indicated that the Waipara River fishery has declined over the years as a number of landowners recalled catching trout in the Waipara during their youth.

The North Canterbury branch of Fish and Game have submitted on a number of the surface water abstraction consents in the Waipara Area. These submissions have mainly focused on the need to preserve fish passage and adequate minimum flows in the river.

A meeting was held with a representative of the North Canterbury branch of Fish and Game New Zealand to discuss current issues associated with water management in the Waipara area. Fish and Game expressed concern over the high level of irrigation abstractions from the river and highlighted the need for an increased minimum flow, as it does not believe that the current minimum flow is adequately protecting the ecosystem of the river. In regard to current management, Fish and Game strongly support the need for both regional and catchment plans. The current practice of managing water resources via resource consents is not supported, as it is not holistic, does not look at the bigger picture and has difficulty addressing cumulative effects. The need for improved monitoring and enforcement was also raised.

Fish and Game have recently been involved in two stakeholder processes: (1) to develop a flow regime for the Ashley River, (2) to consider the Central Plains Irrigation proposal. While both processes were considered useful, it was felt that consultation had commenced in an appropriate manner but had been rushed towards the end due to unrealistic timeframes. The numerous bureaucratic layers within a number of the organisations associated with resource management in New Zealand, is seen as a hindrance to good consultation.

7.4.6 Hurunui District Council

Under Section 31 of the RMA, the Hurunui District Council (HDC) is given responsibility to achieve integrated management of the effects of the use, development, or protection of land and associated natural and physical resources within the Waipara area. In relation to water, the HDC's only direct function under the RMA is to control activities on the surface of rivers and lakes. However, by controlling land-use, HDC indirectly influences water use. The subdivision of rural land for lifestyle and residential development leads to an increase in domestic water usage. The establishment of intensive livestock farming leads to increased demand for stock water, and the establishment of horticultural and viticultural activities requires irrigation water. The establishment of forestry affects the areas' hydrology by increasing evapo-transpiration and reducing runoff (Fahey and Rowe, 1992).

Interviews were held with both the Mayor (John Chaffey), and the Engineering Services Manager (Bruce Yates) to discuss the current issues associated with water management in Waipara. The HDC realise that water is a major issue in the Waipara area and that it directly affects economic growth and development of the district. The HDC believe that development within the district over the next 10 years will be focused on horticultural and viticultural activities. Such activities generally require water for irrigation, and lack of water is seen as the major limitation to development.

In response to a strong community desire to develop the area's water resources, the HDC facilitated the establishment of the 'Water for Waipara' group in August 1998. The group consists of community and HDC representatives and has held numerous meetings to discuss the identification and development of the water resources of the Waipara area. The group has looked at both the development of the groundwater resources of the Waipara Alluvial Basin (Loris, 2000) and is currently investigating water harvesting of flows in the Waipara River and the potential to import water from the Hurunui Catchment.

The HDC operates various water supply schemes throughout the Waipara area (Chapter 6), for which they hold resource consents from Environment Canterbury to abstract water from the Hurunui, Waitohi and Ashley Rivers, and from groundwater near the Waipara Township and south east of Amberley. To satisfy increasing demand for water from the rural water supply schemes HDC has a programme of ongoing maintenance and upgrades. Recent upgrades have extended coverage on the Glasnevin Flats to cater for the recent subdivision of numerous larger properties into smaller lifestyle units. The HDC is confident that the rural water supply schemes will be able to meet future demands for domestic and stock water throughout the area. The HDC's only current concern regarding the rural water supply schemes is related to water quality.

A water supply committee consisting of HDC representatives and elected landowners is responsible for management of each of the rural water supply schemes. Applications for new connections are determined by the water supply committee who then make recommendations to the Works and Services Committee of the HDC. Landowner interviews revealed that they strongly support the water committees and appreciate the fact that applications to join the schemes are discussed by their peers prior to presentation to the HDC.

In regard to water management, HDC see the lack of both information on the area's water resources and a plan for the catchment as a major concern. The rapid development of the area over the last 10 years in the absence of a catchment plan, has created uncertainty for the community (particularly developers) and has made it difficult for the HDC to plan land-use development. Given the link between land-use and water use, there is need for strong links between the HDC and Environment Canterbury particularly in regard to planning, resource allocation and consenting.

7.4.7 ENVIRONMENT CANTERBURY

As outlined in Section 7.3, Environment Canterbury is responsible under Section 30 for the RMA for promoting of the sustainable management of the water resources of the Canterbury Region. Environment Canterbury's current policy and procedures in this regard are outlined in section 7.3. An interview was held with the Planning Manager (John Glennie) to discuss both the water allocations sections of the NRRP and catchment planning in Waipara.

Environment Canterbury's current philosophy on water management planning is, that the NRRP will provide the framework and determine the management methods to be used, and then catchment plans will be developed to determine the site specific issues. Under the current schedule, the development of a catchment plan for Waipara will commence in 2003 with the aim of having the catchment plan operative by 2005. It is envisaged that the development of the Waipara catchment plan will follow a similar process to that recently used for the Ashley River.

The Ashley River process involved the establishment of a stakeholder group, use of an independent facilitator and the preparation of various reports providing both a description of the hydrology and instream values of the river (Mosley, 2001b), and the implications of various flow regimes (Mosley, 2001a). The stakeholder group was tasked with the development of a flow regime that will be presented to Environment Canterbury for formal recognition under the RMA.

7.4.8 COMMON ISSUES

The issues identified by the stakeholders can be grouped into five main groups each of which is discussed below.

(a) LACK OF A MANAGEMENT PLAN

The lack of a management plan is highlighted as a major issue both in terms of development of the water resources and protection of the environment. A management plan will ensure all landowners are subject to the same rules and will provide certainty so that landowners can plan the development of their properties. A plan will provide an opportunity to consider the environment as a whole, to assess cumulative effects and to ensure the environment is managed sustainably. Under the current system, many of the stakeholders feel as if the issues are repeated with each new consent application.

(b) Consultation and Local Input

The development of a Catchment Plan must involve a thorough and appropriate consultation process. It is felt that there is a lack of local input into the current resource consent process. It was suggested that landowners should be responsible for implementation of the Catchment Plan.

(c) Future Water Demand and Efficient Water Use

Given the limited water resources of the Waipara area, there is a need for them to be put to the best possible use. Water users must use water efficiently and grow appropriate crops.

(d) River Flow and Water Level Regime

A flow, water level and water allocation regime is required for the catchment. The regime should both protect the environment and give abstractors certainty over the availability of irrigation water.

(e) Lack of Understanding of the Water resources and the Environment

The lack of understanding of both the water resources (particularly groundwater) and the general environment of the Waipara area is seen as a major restriction to both sustainable management of the water resources and their efficient development.

7.5 RECOMMENDATIONS FOR MANAGEMENT

The management of Waipara's water resources is continually evolving and this study is part of that evolution. Based on the information presented in the previous chapters, the following recommendations are made to assist in the sustainable management of the Waipara's water resources under the RMA. It is realised that the implementation of the recommendations will take time due to the significant economic, social and political issues surrounding water management in Waipara. The recommendations have been developed with consideration of these wider issues and it is suggested that the recommendations (while being idealised outcomes) could realistically be implemented over the next 5-10 years.

7.5.1 GENERAL WATER MANAGEMENT

(a) CATCHMENT PLAN

A detailed catchment plan which covers all the aspects of catchment management (water quantity, water quality, land-use, soil conservation etc.) is vital to the holistic management of the Waipara's resources. Environment Canterbury's commitment to producing such a plan is strongly supported by all the stakeholders, all of which indicated that they would like to be actively involved in the process. Given the linkages between: groundwater and surface water, land-use and water quantity and quality, it is suggested that the process will need to be significantly broader than the process recently undertaken for the Ashley River. An extensive consultation process with all stakeholders will be necessary to ensure that the catchment plan is supported by all.

(b) USER GROUPS

The establishment of a water user/landowner group to oversee implementation of water allocation schemes is strongly encouraged. Such a group would greatly assist management, ensure that the water resources of the Waipara area are put to the best possible use and provide the local community with the desired control of local water management. It is suggested that the 'Water for Waipara' group and the 'Omihi Irrigation Society' together with the addition of existing water users could form the basis of a user group. The user group should operate in a similar manner to the water committees who manage the rural water supply schemes. The user group should be responsible for ensuring that the flow, water level and water allocation regime (established via a catchment plan) is implemented appropriately. The user group should also be tasked with compliance monitoring of resource consents and the preliminary assessment of resource consent applications. This would have the advantage of providing Environment Canterbury with more time to concentrate on understanding the environment and environmental monitoring.

(c) RESOURCE CONSENTS

Water permits granted in the Waipara catchment and on the Glasnevin Flats should have common expiry dates and common 5 yearly review conditions which allow cumulative effects and appropriate water use to be assessed. Given that the water resources of the catchment are highly allocated, the complicated nature of the aquifers, the limited recharge rates and the lack of long-term monitoring information, a ten to fifteen year consent duration is suggested. While this is substantially less than the 35 years currently applied to groundwater abstraction consents, it should provide landowners with sufficient certainty and is in line with the 12 year duration placed on most of the area's surface water abstraction consents.

The large number of water abstraction consents which were not exercised in 2000-2001 and the low level of actual use indicates that allocation often far exceeds need. It is suggested that the current resource consents need to be reviewed to better reflect actual water needs and to implement the minimum flows suggested below.

To overcome the current situation where upstream users can effectively reduce a downstream user's ability to abstract, it is suggested that the water users/local landowners group should be given the authority to control the exercise of abstraction consents. This is a significant departure from the current system where by individual abstractors are only responsible to Environment Canterbury, however in a water short area like Waipara it is considered necessary.

(d) EFFICIENT USE

Peer pressure (via user/landowner groups responsible for the implementation of water allocation regimes) and farm economics are expected to ensure water is used efficiently.

7.5.2 SURFACE WATER MANAGEMENT

(a) MINIMUM FLOWS

The establishment of a minimum flow is a key issue in protecting the instream environment and providing certainty to abstractors. The current system of 6 minimum flow sites is ad hoc and difficult to implement. New Zealand MfE (1998) recommends that the process by which minimum flows are established should include:

- identification of the instream values that are to be sustained,

- determination of the instream management objective,
- identification of the critical factors that will effect the management objective, and
- determination of the flow requirements that will meet and sustain the management objective.

In a study on the fishery values of the Waipara River, Richardson (1994) found that eight species of native fish inhabit the Waipara River, and that the upper catchment (above White Gorge) and the river below State Highway 1 (SH1) have the highest fishery values. It is suggested that the upper catchment (above White Gorge) and the lower catchment (below the confluence of Omihi Stream) should be managed for native fish, while the middle section of the Waipara River, Omihi Stream, Home Creek and Weka Creek should be managed for mauri. This is consistent with both the direction given by the draft NRRP and the concerns raised by the stakeholders.

In implementing a minimum flow regime, two issues need to be addressed: the section of the river for which the minimum flow will apply and the level of the minimum flow. To account for the significant contribution Omihi Stream has on summer flows in the lower reaches of the Waipara River, it is suggested that the minimum flow below the confluence of Omihi Stream should be based on flow at the Teviotdale flow recorder. While it is not ideal to establish a minimum flow regime which is based on flow measurements upstream of abstractors, it is suggested that the minimum flow for the main Waipara River down to the confluence of Omihi Stream should be based on flow at White Gorge.

(i) The lower reaches of the Waipara River below the Omihi Stream confluence

In a study on the minimum flow for native fish in the Waipara River, Jowett (1994) suggested a minimum flow of 140 l/s would be sufficient to maintain acceptable habitat for native fish in the lower Waipara River. This is substantially above the current minimum flow of 80 l/s; however Jowett found that at 80 l/s there is little suitable habitat for either torrent fish *(Cheimarrichthys fosteri)* or bluegill bullies *(Gobiomorphus hubbsi)*. During the 2000-2001 summer the existing minimum flows were not reached but the river went dry below the Teviotdale Bridge (Figure 4.7) significantly compromising instream ecology. It is suggested that the minimum flow for the Waipara River below the confluence of the Omihi Stream should be 140 l/s as measured at the Teviotdale Recorder.

(ii) The middle and upper reaches of the Waipara River

Between February 1988 and April 2001, flow in the Waipara River at White Gorge dropped below the current minimum flow of 50 l/s for a total of only 67 days (1.4 % of the time). Given that this period included the significant droughts of 1988-89 and 1998, the infrequent occurrence of the minimum flow indicates that it is set too high. The establishment of a minimum flow regime is a very complex issue (New Zealand MfE, 1998) made more difficult in Waipara due to the lack of information on the relationship between flow and fishery habitats in the upper catchment, and mauri in the middle catchment makes the process more complex for the upper and middle sections of the Waipara River. As an interim measure, it is suggested that the mean annual 7-day low flow (MALF) should be utilised as the minimum flow. This is consistent with information presented by DOC in regard to the Ashley River and by Fish and Game in regard to the water conservation order for the Rangitata River in South Canterbury (New Zealand Fish and Game Council, 1999). In an integrated water resources management study currently being undertaken on the Motueka River (Nelson, New Zealand) MALF was found to provide very good protection for brown trout habitat (Bowden, 2002). Minimum flow should be established for individual situations and general rules of thumb are not transferable (New Zealand MfE, 1998); however the Ashley, Rangitata and Motueka rivers give some guidance.

The 1989-2000 mean annual 7-day low flow in the Waipara River at White Gorge is 88 l/s. This is 38 l/s higher than the current minimum flow (50 l/s), and if adopted will lead to a reduced security of supply for abstractors. During the period March 1988 to April 2001, mean daily flow dropped below 88 l/s on average 11 times a year (Table 4.2 Chapter4), which is compared with an average of 6 times a year for 50 l/s. This five day increase (in the average annual period when minimum flows would restrict abstraction) is not expected to significantly compromise abstractors, especially if water harvesting of flood flows is encouraged to augment abstractions during low flow. To acknowledge inaccuracies in the measurement of river flow it is suggested that the minimum for the Waipara river between White Gorge and the Omihi Stream confluence should be 90 l/s as measured at White Gorge.

(iii) Omihi Stream, Home Creek and Weka Creek

Large sections of Omihi Stream, Home Creek and Weka Creek are ephemeral during the dry summer months under current land-use conditions. Given this ephemeral nature, one could question the appropriateness of establishing minimum flows for these watercourses. However, the significance of inflow from Omihi Stream on summer flows in the lower Waipara river and the significant recharge the area's groundwater resources receive via seepage from these watercourses, highlights the need to protect them from over abstraction. Discharge rates from the substantial springs adjacent to Omihi Stream immediately above Glenray Farm Bridge, are expected to represent the health of both the three watercourses and their associated shallow groundwater systems. It is suggested that minimum flows for particularly the Home Creek and Omihi Stream catchments should be based on flow from the springs. Flow in Weka Creek has been substantially altered by the construction of the Glenmark Irrigation Scheme. The scheme was developed following a thorough investigation of the water resources of the catchment (Harrington, 1976; Heiler et al., 1977) which involved the establishment of a minimum flow. The scheme is constructed so that during normal flows water passes through the intake structure with the minimum flow returned to the river. Given that the current allocated abstractions from Weka Creek are for water harvesting of flood flows, the significance of minimum flows is somewhat reduced.

(iv) Implementation

In implementing minimum flows, consideration must be given to downstream users. Under the current system, the potential exists for downstream users to abstract all the water in the river without breaching the conditions attached to their abstraction consents. Similarly, upstream users can effectively reduce the downstream user's ability to abstract, therefore creating an artificial priority of usage. This issue was discussed during the Environmental Court hearing for water permit CRC 950255 to abstract water from the Waipara River (RMA W100/95, 1995). The Environment Court concluded that priority must be given to existing users and conditions were attached to the abstraction to ensure this. Rather than use consent conditions to implement water allocation, it is suggested that the water users/local landowners group should be tasked with implementation of the allocation regime. It is envisaged that the user group as a whole would be allocated water from the areas watercourses and the group would then determine how the allocation was to be shared amongst its members. This will allow users to schedule their water use to take best advantage of the flows in the river, encourage efficient water use through peer pressure and will help satisfy the desire by many local landowners for more control over the water resources of the area.

(b) MAXIMUM ALLOCATED VOLUME

To ensure variability of flows in the Waipara River, an allocation regime is necessary. Variability of flow is essential to stream health and protecting the mauri of a waterbody (Environment Canterbury, 2001; Te Runanga o Ngai Tahu, 1999; New Zealand MfE, 1998). Ideally an allocation regime should involve both a sharing of flow between instream values and abstractions and an abstraction limit. Under the current system, existing abstractors would (if they all abstracted concurrently and at every opportunity) hold flow in the Waipara River at 50 l/s for approximately 110 days per year (Table 7.6) which is excessive. The draft NRRP suggests an allocation limit of only 26 l/s which is considered unrealistic given that 270 l/s is currently allocated from the Waipara River during the summer months. As an interim measure it is suggested that the first 100 l/s above the minimum flow should be allocated for abstraction, and then a 50 % sharing between abstraction and instream values. Of the 270 l/s currently allocated, consents covering only 145 l/s were actually exercised over the 2000-2001 summer. Given that most of the abstractions are not continuous and given that they usually don't occur concurrently, it is suggested that the 100 l/s should be sufficient to cover existing actual use. It is noted that from early February to late March 2001 flow in the Waipara River at White Gorge was constantly below 100 l/s. During this time irrigators who have a combined allocation of 145 l/s were able to irrigate without any problems suggesting that actual use is was well below the 145 l/s. The suggested allocation scheme would cause flow in the Waipara River to be held at 90 l/s (approximately MALF) for slightly over 2 months (69 days) per year. Similarly, the allocation regime would encourage harvesting of high flows which is seen by the author as the most sustainable method for increasing irrigation in the area.

Table 7.6 Implication of differing Allocation rates on flow in the Waipara River

Approximate Flow in the Waipara River between White Gorge and the confluence of Omihi Stream		**Proportion of time Flow below value**	
Description	l/s	(%)	Days per year
Current minimum flow	50	2	7
Suggested Minimum Flow (MALF)	90	7	26
Existing minimum flow plus 100 l/s continuous abstraction	150	15	55
MALF plus 100 l/s continuous abstraction	190	19	69
Existing minimum flow plus 200 l/s continuous abstraction	250	24	88
MALF plus 200 l/s continuous abstraction	290	25	91
Current situation Existing minimum flow plus 282 l/s current allocated during summer.	370	30	110

7.5.3 GROUNDWATER MANAGEMENT

The draft NRRP indicates that groundwater allocation will be managed so that there is no long term decline in mean annual groundwater levels. The lack of historic water level readings (particularly from the deeper semi-confined to confined aquifers) makes it impossible to assess current trends in water levels. The situation is further complicated by pumping effects which reduce the reliability of many of the monthly water level readings. Its is suggested that it will require 10 years of monthly readings before trends in groundwater can be determined with any certainty. This raises the possibility that significant long term decline may have already occurred by the time we have enough data to accurately assess trends. It is suggested that the lack of water level data could possibly be overcome through runoff and soil moisture simulation models which utilise the extensive precipitation records that are available.

To sustainably manage the groundwater resource, the volume abstracted annually should be no greater than the average annual recharge. The Draft NRRP suggests that the maximum allocation should be 50% of the annual recharge. Groundwater recharge is variable throughout the Waipara Basin with significant recharge only likely to occur adjacent to Omihi Stream, Home Creek and Weka Creek (Section 5.4.5). The estimated average annual recharge to the Canterbury Teviotdale gravel aquifers in the Waipara Alluvial Basin is between 19 and 24 million m^3 (Section 5.4.6) of which a minimum of 6 million m^3 is required to cover normal summer decline in the unconfined aquifers, leaving a maximum of between 13 and 18 million m^3 which could potentially be available for abstraction. Current groundwater allocations already represent between 18% (18 million m^3 recharge) and 25% (13 million m^3 recharge) of the estimated maximum recharge. Given that recharge is very variable throughout the Waipara Alluvial Basin (Chapter 5.4.5) it is suggested that further allocation of groundwater in all parts of the Waipara Alluvial Basin other than adjacent to Omihi Stream, Home Creek and Weka Creek should proceed with caution. Continuation of the recent rapid development of the area's groundwater resources is expected to result in over allocation of the groundwater resources.

7.5.4 ADDITIONAL INFORMATION

Lack of a thorough and complete understanding of the water resources of the Waipara catchment makes management of the resources extremely difficult. It is hoped that this study in association with current work being undertaken on the groundwater of the Omihi Valley (Finnemore and Pettinga, in press) and the presence of periphyton growths in the Waipara River (Hayward, in press), will assist understanding and facilitate management. This study has identified a number of areas where additional investigation would be useful which are outlined in the following chapter.

In regard to the current monitoring programme the following suggestions are made.

(i) Surface Water

Given the significant contribution flow from Omihi Stream has on low flows in the lower Waipara River, it is suggested that a continuous flow monitoring site be established below the Glenray Farm Bridge. This would have the additional benefit of monitoring discharge from the springs in the area, which would give an indication of the health of the area's shallow ground water system.

(ii) Groundwater

Continuous water level monitoring undertaken as part of this study indicated that water levels in many parts of the Waipara Alluvial Basin are strongly affected by pumping, which reduces the usefulness of monthly point measurements. It is suggested that at least two continuous water level monitoring sites be established and the current monthly water level monitoring programme revised. Given both the lack of historic water level data from the deeper semi-confined and confined aquifers and the increasing use of these aquifers, the monthly water level monitoring programme should target boreholes which penetrate these aquifers.

(iii) Compliance Monitoring

There is a general lack of compliance monitoring of consent conditions, minimum flows, abstraction rates and actual water use within the Waipara Catchment. It is suggested that compliance monitoring should be delegated to a user group with external auditing from Environment Canterbury.

7.6 SUMMARY

This chapter summaries the existing water management structure operative in the Waipara area. Based on analysis of the current management issues and using the information generated in the previous sections, various recommendations on future management have been made. The key findings in regard to water management in Waipara Catchment are:

- Water management in the Waipara catchment falls under the jurisdiction of Environment Canterbury and the legislative frame work of the Resource Management Act 1991.

- Environment Canterbury's current policies on water management are summarised in the draft chapters of the Canterbury Natural Resources Regional Plan. Environment Canterbury currently plans to develop a flow, water level and allocation regime for the Waipara River by 2005.

- Current water management in Waipara is based on the imposition of minimum flow conditions attached to abstraction consents. The current minimum flow levels for the main Waipara River are insufficient to adequately protect instream ecology, particularly fish habitat.

- Significant land-use change is predicted throughout the Waipara Catchment over the next 25 years. Much of this land-use change will directly affect water management including the predicted afforestation of approximately 5000 ha, a tripling of the area currently in viticulture and a large increase in the area irrigated.

- Five major water management issues were identified.
    1. The need for a comprehensive management plan covering the catchment.

2. The need for extensive consultation in the development of the management plan and a desire by landowners to have control of implementing the plan.
3. The need for efficient and appropriate use of the area's water, particularly given that demand for water is projected to increase.
4. The need to develop a flow and water level regime that both protects instream values and provides abstractors with certainty of water supply.
5. The need to improve knowledge of the areas water resources through monitoring and research.

- The following management recommendations were made.
  1. A holistic Catchment Plan for the Waipara catchment should be developed through an extensive consultation process. Such a plan should cover both groundwater and surface water and the linkage between land-use and water quantity/quality.
  2. A water user/landowner group should be established for the Waipara area to control implementation of the catchment plan. The user/landowner group should control the exercising of abstraction consents in the areas, be tasked with compliance monitoring of consent conditions, and undertake preliminary assessment of new consent applications.
  3. The minimum flow in the main Waipara River above the confluence of Omihi Stream should be 90 l/s (approximately the 7-day mean annual low flow) as measured at the White Gorge flow recorder. The minimum flow below the Omihi Stream confluence should be 140 l/s as measured at the Teviotdale flow recorder site. Minimum flows in Omihi Stream, Home Creek and possibly Weka Creek should be based on discharge from the substantial springs immediately above the Glenray Farm Bridge.
  4. The first 100 l/s above the minimum flows should be available for abstraction above which there should be a 50 % sharing between abstraction and instream values.
  5. Groundwater allocation should be based on the average annual recharge rates. For the Canterbury/Teviotdale gravel aquifers of the Waipara Alluvial Basin, maximum average annual recharge is estimated at between 19 and 24 million m^3. However, recharge is highly variable throughout the basin and it is suggested that further allocation of groundwater in all parts of the Waipara Alluvial Basin other than adjacent to Omihi Stream, Home Creek and Weka Creek should proceed with caution.
  6. Environment Canterbury's current monitoring programmes, particularly groundwater monitoring in the Waipara area, need to be revised to assist the management of the area's water resources.

In producing the above management recommendations, the main objective of this study has been completed. The following chapter represents a brief summary of the key findings and outlines the areas where further work is required.

SECTION FOUR

SUMMARY AND CONCLUSIONS

8 CONCLUSIONS

8.1 AIMS

This study was undertaken to provide information on the extent of the water resources of the Waipara catchment and the issues associated with their allocation and management. The four major aims of this study were:

1. To accurately describe the water resources of the Waipara Catchment.
2. To identify current water use.
3. To outline the main water management issues.
4. To make recommendations on future management.

The main findings (which have already been summarised in point form at the end of appropriate chapters) are broadly stated below and their implications examined.

8.2 SUMMARY OF FINDINGS

8.2.1 RESOURCE DESCRIPTION

To accurately describe the water resources of the Waipara Catchment, information was collected and analysed on the climate, surface water resources and groundwater resources of the Waipara Catchment. This allowed a water balance to be completed to determine groundwater loss from the catchment and a resource summary to be presented for the water resources under both winter and summer conditions (Chapter 6). The water balance revealed that of the 771 mm/yr of average annual precipitation, 475 mm/yr is returned to the atmosphere via evapo-transpiration and 212 mm/yr flows out to sea via the Waipara River which results in a net groundwater movement out of the catchment of 85 mm/yr. While the imbalance of 85 mm/yr in the average water balance may result from errors in the estimates of precipitation, evapo-transpiration and river flow, the residual is thought to be real and to indicate significant groundwater losses from the catchment. It is suspected that much of the ground water movement out of the catchment is via flow though the tertiary strata particularly in the Omihi Stream catchment.

(a) CLIMATE

(i) Precipitation

There is considerable spatial variation in precipitation throughout the Waipara area and five precipitation zones were identified: (1) the Coastal Hills, (2) the flanks of Mount Grey (3) the Okuku Range, (4) the Doctors Hills and Weka Pass, and (5) the Omihi Valley and Waipara

Township. While precipitation amounts are broadly related to elevation, local influences such as rain-shadows and windflow directions also play a significant role. A large section of the central Waipara catchment (Omihi Valley, Weka Pass and the Doctors Hills), receive limited rainfall due to precipitation shadows created by the Coastal Hills in the east, and Mount Grey and Mount Karetu to the south. Mean annual 1951-2000 precipitation varies from 625mm in Balmoral and Waipara Township to over 1400 mm on the summit of the Okuku Range. Precipitation is evenly spread throughout the year with most of the precipitation falling during localised high intensity storms. Conversely, annual precipitation is highly variable and is controlled by regional weather patterns.

Based on precipitation records from 14 sites, the 1951-2000 mean annual precipitation for the Waipara Catchment was 771 mm/yr ± 5 %, of which the upper catchment received 51% (838 mm/yr over 331 km^2), Omihi Stream and Home Creek 23 % (772 mm/yr over 157 km^2) and Weka Creek 11% (693 mm/yr over 87 km^2).

(ii) Evapo-transpiration

The water resources of the Waipara area are dominated by the effects of evapo-transpiration which causes low flows in the area watercourses and significant soil water deficits during the summer months. Actual evapo-transpiration rates range from slightly over 400 mm/yr to approximately 550 mm/yr throughout the catchment. Actual evapo-transpiration is limited by the availability of water particularly during the summer months and is strongly influenced by the variability of soils throughout the catchment. High rates of evapo-transpiration during the summer months, lead to significant soil moisture deficits that limit vegetation growth and create a large demand for irrigation water particularly in the Waipara basin. Significant evaporation occurs from the area's waterbodies with many small stock water dams drying up over the summer. However, because of the limited area of the waterbodies, evaporation of surface water makes a small contribution to the catchment water balance.

(b) Surface Water

The flow pattern in the watercourses of the Waipara catchment is strongly seasonal and while the 1989-2000 mean annual flow in the Waipara River at the White Gorge recorder was 3148 l/s, mean monthly flows varied from 520 l/s during January to 7285 l/s during July. Utilising a runoff model, the 1951-2000 mean annual flow was calculated at 3308 l/s which suggests that the 1989-2000 was slightly drier than the long-term average (confirmed by precipitation records). Flow in the Waipara River is characterised by long periods of low flow and large infrequent short duration flood events which reflects the lack of storage within the catchment and the storm related nature of the area's precipitation. During periods of low flow, Omihi Stream contributes approximately 50% of the flow that passes the Teviotdale recorder site, while at times of high flow, runoff from the upper catchment becomes dominant.

There is considerable variation between the surface watercourses of the area in regard to their connection with groundwater. The Waipara River gains flow from tributary inflow over most of its length, and is not significantly connected to groundwater other than below the Teviotdale Bridge and in small sections of the upper catchment. Flow in Weka Creek, Home Creek and Omihi Stream is strongly connected to groundwater with significant gains and losses to and from groundwater.

(c) GROUNDWATER RESOURCES

Historically, the search for groundwater in the Waipara area has focused on relatively small semi-permeable to permeable old buried river channels within the Canterbury Gravel and Teviotdale Gravel deposits. The aquifers are of limited thickness (generally <10m), are not laterally extensive, do not transmit water very fast (transmissivity ranges between 18-92 m^2/day) and when pumped, experience large drawdowns. Water yields from the wells and boreholes in the area are generally low, with yields greater than 10 l/s the exception rather than the rule.

A recent borehole has suggested possible additional aquifers within the deeper Tertiary rock units of the area. This is supported by the presence of sinkholes and the identification of losses in flow where the watercourses cross Tertiary rock units.

Regular, relatively small scale pumping, results in water levels over large areas of the Glasnevin Flats being held at an artificially lower level for long periods over the summer months. Boreholes in the area have long recovery rates and generally do not fully recover between pumpings. Well interference effects and induced drawdowns are significant in the closely spaced wells and boreholes in the new subdivisions on the Glasnevin Flats.

Groundwater recharge throughout much of the area is both limited and extremely slow due to low precipitation, high evapo-transpiration rates, the presence of fragipans in the soil profile and the low permeability of the clay bound gravels that dominate the area. Seven recharge categories were identified for the gravel aquifers of the Waipara Alluvial Basin, of which only one (the confined and semi-confined aquifers adjacent to Home Creek, Omihi Stream and Weka Creek) is expected to have significant recharge. Upward movement of groundwater, from within the Tertiary rock units along fault and fracture surfaces is expected to recharge some of the deeper gravel aquifers. Excluding the upward movement of deep groundwater, the estimated average annual recharge to the Canterbury/Teviotdale gravel aquifers in the Waipara Alluvial Basin is between 19 and 24 million m^3.

8.2.2 CURRENT WATER USE

An extensive process of landowner and water user interviews allowed actual water use within the Waipara area to be assessed for the first time. While this process did not involve actual measurement of individual abstractions, landowners were able to give good estimates of their actual water use during the 2000-2001 summer. When compared to the volume of water allocated by Environment Canterbury under current resource consents, this information highlights the fact that water allocation is often far in excess of actual use. It is noted that while heavy rain in October and November 2000 delayed the start of the summer irrigation season, the lack of rain in autumn resulted in an extension of the irrigation season and overall the 2000-2001 summer was considered fairly typical in terms of water use.

(a) SURFACE WATER

The surface water resources of the Waipara Catchment are highly utilised with a total of 1491 l/s currently allocated via 28 resource consents. In addition, numerous properties tap springs and abstract surface water under Environment Canterbury's General Authorisations. Water abstractions from Home Creek, Weka Creek and Omihi Stream are generally for water harvesting of high flows and occur predominantly during the winter, while water abstractions from the Waipara River are dominated by summer abstractions. During summer, the main Waipara River is over allocated, with potential abstraction rates exceeding normal summer supply. Under the current regime (when the flow in the Waipara River at White Gorge is immediately above 50 l/s), the downstream users are authorised to abstract 184 l/s or three times the actual water available. It is noted that of the 360 l/s which has been allocated from the watercourses of the Waipara area for direct summer irrigation, only 164 l/s or 46 % was actually exercised during the summer of 2000-2001.

Rural water supply schemes cover a large part of the Waipara Catchment and import approximately 900 m^3 of water into the catchment per day for domestic and stock water requirements. Without the schemes, the viability of a number of the properties in the areas would be seriously compromised.

(b) GROUNDWATER

Since 1996, rapid development of the area's groundwater resources has occurred. Current allocation of groundwater from the Canterbury/Teviotdale Gravel Aquifers, stands at 18 013

Based on information generated during this study the following management recommendations were developed to address the current management issues and to ensure that the water resources of the Waipara Area are managed in a sustainable manner under the RMA. The initial recommendations cover broader scale policy issues and then flow on to cover the specifics of implementation in Waipara.

(a) Catchment Management Plan

A holistic Catchment Plan for the Waipara catchment should be developed through an extensive consultation process. Such a plan should cover both groundwater and surface water, the linkage between land-use and water quantity/quality and include a flow, water level and allocation plan. As the catchment plan will fall under the framework of the RMA, its development will be subject to the extensive consultation requirements of the RMA. Given the high level of interest and concern regarding the water resources of the area, it is suggested that a stakeholder group be established to assist in the development of the catchment plan. Such a stakeholder group should be facilitated by Environment Canterbury and include representation from: local landowners and water users, Ngāi Tūahurirri Rūnanga, the Department of Conservation, the Royal Forest and Bird Society, the Fish and Game Council and the Hurunui District Council.

(b) Water Users / Landowners Group

A water user/landowner group should be established for the Waipara area to control implementation of the catchment plan. The user/landowner group should have authority to control the exercise of abstraction consents and be tasked with: scheduling abstractions to meet the flow and allocation regimes, compliance monitoring of consent conditions, and the preliminary assessment of new consent applications. It is envisaged that the user group as a whole would be allocated water from the areas watercourses and the group would then determine how the allocation was to be shared amongst its members. This will allow users to schedule their water use to take best advantage of the flows in the river and encourage efficient water use through peer pressure. Such a group would ensure 'hands on' management of the areas water resources and provide the local community with the autonomy it desires for local water management.

(c) Water Use

The large number of water abstraction consents which were not exercised in 2000-2001 and the low level of actual use indicates that allocation often far exceeds need. It is suggested that the current resource consents need to be reviewed to better reflect actual water needs and to implement the suggested minimum flows and allocation regime outlined below.

(d) FLOW, WATER LEVEL AND ALLOCATION REGIME

(i) Minimum Flows

In developing a flow regime for the watercourses in the Waipara area, the principle concern is the establishment of suitable minimum flows. For the main Waipara River, it is suggested that the minimum flow should be 90 l/s (as measured at White Gorge) for that section of the river from White Gorge down to the Omihi Stream confluence and 140 l/s (as measured at the Teviotdale recorder) below the confluence of Omihi Stream. Minimum flows of this magnitude will adequately provide for native fish habitat in the lower reaches of the river while not significantly compromising existing abstractions from the river. Minimum flows in Omihi Stream, Home Creek and possibly Weka Creek should be based on discharge from the substantial springs immediately above the Glenray Farm Bridge. Discharge rates from the springs are expected to represent the health of the three watercourses and their associated shallow groundwater systems. In order to implement this minimum flow, there is need to establish a continuous flow recorder at or near the Glenray Farm Bridge. The minimum flows need to be implemented in a manner where the minimum flow is maintained for the whole of the reach and existing abstraction consents should be reviewed to ensure this is achieved.

(ii) Surface Water Allocation Regime

In regard to the development of a surface water allocation regime, it is suggested that in the main Waipara River the first 100 l/s above the minimum flows should be available for abstraction, above which there should be a 50 % sharing between abstraction and instream values. Such a regime would safeguard the current level of actual water usage while encouraging water harvesting of flood flows to augment abstractions during low flows.

(iii) Groundwater Allocation Regimes

The volume of water allocated from groundwater should be based on average annual recharge rates. For the Canterbury/Teviotdale Gravel aquifers of the Waipara Alluvial Basin average annual recharge is estimated at between 19 and 24 million m^3. However, recharge is highly variable throughout the basin and it is suggested that further allocation of groundwater in all parts of the Waipara Alluvial Basin other than adjacent to Omihi Stream, Home Creek and Weka Creek, should proceed with caution.

(e) ALTERNATIVE SOURCES OF WATER

Summer flows in the watercourses of the Waipara area are already over allocated. Similarly groundwater recharge throughout much of the area is limited. To overcome this, water harvesting of high flows to augment water abstraction during summer low flows should be promoted.

(f) MONITORING AND RESEARCH

Environment Canterbury's current monitoring programmes in the Waipara area (particularly groundwater monitoring) need to be revised to assist the management of the water resources. Suggested improvements to the monitoring programmes are given in Chapter 7.5.3. Similarly recommendations for further investigations are given in Section 8.5 below.

8.2.4 PRESENTATION OF FINDINGS

Wherever possible ArcView GIS (Geographical Information Systems) has been used to store and present the data. This has ensured that the information is easily accessible and will allow future studies to readily use the data that have been generated.

8.3 IMPLICATIONS OF FINDINGS

The main implications of the findings are that the water resources of the Waipara area are very limited, already highly allocated, and likely to face increasing demand for their use and development. Given the large potential the area has for horticultural and viticultural development, water managers are going to face increasing challenges as they balance instream values against out-of-stream uses. To overcome the current over allocation of summer flows in the area's watercourses, there is a need to ensure efficient water use and to encourage water harvesting of high flows to augment summer abstractions. Similarly, the low groundwater recharge rates for most of the Waipara area indicates that further allocation of groundwater should proceed with caution. Continuation of the recent rapid development of the area's groundwater resources is expected to result in over allocation.

8.4 FURTHER INVESTIGATIONS

This study has helped to describe both the water resources of the Waipara area and the numerous issues associated with their management. In order for our understanding to be refined further, the following investigations should be undertaken.

(a) *CLIMATE*

A precipitation gauge should be established at a high elevation (possibly the top of Mount Grey or Mount Karetu), to allow improvement of the rainfall elevation model.

The soil water measurements (neutron probes) currently being undertaken by numerous landowners in the area should be used to refine the estimate of actual evapo-transpiration in the areas which are irrigated.

(b) *SURFACE WATER*

A gauging run along the main Waipara River at high flow to assess tributary inflow should be undertaken, to compliment the low flow and medium flow gauging runs undertaken during this study. Also a detailed gauging run between Laidmore Road and White Gorge to identify any losses to groundwater.

The runoff model for Weka Creek (developed for the Glenmark Irrigation Scheme) should be updated along with the development of models for Omihi Stream and Home Creek. Such models would greatly assist in the establishment of minimum flows, especially given the extensive precipitation records that are available.

For the major springs immediately above Glenray Farm Bridge, chemical analysis, tracer studies and monitoring of discharge rates should be investigated to confirm that the springs are directly connected to surface water flows in Home Creek, Omihi Stream and Weka Creek.

Baseflow regression analysis of the flow data from both the White Gorge and Teviotdale recorder sites should be carried out. This would further clarify the significant contribution flow from Omihi Stream has on low flows at the Teviotdale recorder.

(c) *GROUNDWATER*

Aquifer tests are required to determine aquifer properties throughout the basin and to explain the presence of a number of boreholes in the Waipara Alluvial Basin which have unusually high yields and high artesian pressures. As an initial priority, such tests should target the confined aquifers adjacent to Omihi Stream, Home Creek and Weka Creek.

Chemical analysis and dating of groundwater should be undertaken for the recharge zones identified in this study and should be comparable with the earlier work undertaken by Loris (2001).

Seepage tests of the bed of the Waipara River and the continuous monitoring of water levels in a borehole adjacent to the river should be done to confirm the lack of groundwater surface water interaction.

Seepage tests of the bed of Omihi Stream, Home Creek and Weka Creek and the continuous monitoring of water levels in boreholes adjacent to the three systems, should be done to confirm that groundwater is directly connected to surface water in those zones, and to further estimate flow losses to groundwater.

(d) *WATER BALANCE*

A quantitative water balance model should be developed for the Waipara Catchment using GIS (Geographical Information Systems) technologies and simulation models (e.g. Topnet, IQQM). Such a model would enable better assessment of the consequences of spatial heterogeneity. The model should be used to predict likely future water balances for the Waipara catchment to assess the effects of the predicted future land-use changes, differing water allocation regimes and the potential effects of climate change.

(e) *WATER MANAGEMENT*

As previously recommended, the completion of a holistic catchment management plan via a thorough consultation process is vital for the efficient and sustainable management of the water resources of the Waipara Catchment.

This study is presented to provide background information on the extent of the water resources of the Waipara catchment and the issues associated with their allocation and management. The water resources of the area are of limited extent and face considerable demand for use and development. Summer flows in the area's watercourses are already over allocated and continued development of groundwater will inevitably lead to over allocation. Similarly current water allocations are far in excess of actual water use. It is hoped that the community and those responsible for water management will use the information presented, to ensure that the water resources of the Waipara catchment are managed in a sustainable and efficient manner.

ABBREVIATIONS

AcrView	A GIS computer program used to manipulate and present information. For this study ArcView GIS versions 3.2a was used.
CRC	Canterbury Regional Council
DOC	Department of Conservation
GIS	Geographical Information Systems
HELP	Hydrology for the Environment, Life and Policy programme. HELP is a joint UNESCO/WMO programme which is designed to establish a global network of catchments to improve the links between hydrology and the needs of society. It is a cross cutting programme of the UNESCO International Hydrological Programme and will contribute to the World Water Assessment Programme (WWAP), and the Hydrology and Water Resources Programme of WMO.
HDC	Hurunui District Council
IQQM	The Integrated Quality and Quantity Model. A planning model, developed by New South Wales Department of Land and Water Conservation that is used to investigate impacts of water resources management options in systems.
MALF	the 7 day Mean Annual Low Flow. In any given year the seven-day low flow is the lowest average flow over seven consecutive days for every seven consecutive day period in the year.
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NRRP	Canterbury Natural Resources Regional Plan currently in draft form
RMA	Resource Management Act 1991
SH1	State Highway 1 where it passes through the Waipara Catchment
Topnet	a catchment model developed by NIWA to predict the effects on river flow of slow changes in vegetation, Topnet makes use of GIS (Geographical Information System) databases and is designed to model a catchment as a collection of sub-basins linked by a branched river network. Other database variables such as vegetation, rainfall, and soil type are used to characterize each sub-basin.
UNESCO	United Nations Educational Scientific and Cultural Organisation

REFERENCES

Al-Daghastani, H. S. Y. and J. K. Campbell, 1995, The evolution of the lower Waipara River Gorge in response to active folding in North Canterbury, New Zealand. *ITC Journal* 1995 3): 246-255.

Australian Representative Basins Program, 1982, Review of the Australian Representative Basins Program. Australian Government Publishing Service, Canberra, Australia.

Borrie, D., G. Pinnell and M. Thomas, 1972, Waipara Irrigation Development Groundwater Investigation. Lincoln College, Lincoln, New Zealand.

Bowden, B., 2002, Integrated Catchment Management for the Motueka River, Tasman District Council, Cawthron Institute and Landcare Research. Available http://icm.landcare.cri.nz/programme_leader/programme_leader_update.htm. 2002.

Bowden, W. B., 1999, Integrated catchment management rediscovered: an essential tool for the new millennium. *Manaaki Whenua Conference*, Te Papa, Wellington, New Zealand.

Brizga, S. and B. Finlayson, 2000, Conclusions: Future Directions. *in River Management - The Australasian Experience*. S. Brizga and B. Finlayson. International Association of Geomorphologists No. 8, Wiley, Chichester, U.K. p 287-294.

Browne, G. H. and B. D. Field, 1985, The lithostratigraphy of Late Cretaceous to Early Pleistocene rock of North Canterbury, New Zealand. New Zealand Geological Survey Record 6, Wellington, New Zealand. p63

Burman, R. and L. O. Pochop 1994. Evaporation, evapotranspiration and climatic data. Elsevier, Amsterdam.

Campbell, D. I. and D. L. Murray, 1991, Water Balance of snow tussock grassland in New Zealand. *in Journal of Hydrology*, v118, p 229-245.

Campbell, J. K. and A. Nicol 1992. Holocene folding and rupture on the Boby's Creek Fault and related Quaternary deformation along the Waipara River. *Field Trip Guides: Geological Society of New Zealand and New Zealand Geophysical Society Joint Conference*, J. K. Campbell, Geological Society of New Zealand. Miscellaneous Publication 63B, Christchurch, New Zealand, p 137-153.

Canterbury Regional Council, 1993, Issues and options for the management of water resources in the Waipara Region, Canterbury Regional Council, Christchurch, N.Z. p66

Canterbury Regional Council, 1995a, Proposed Waimakariri River Regional Plan, Canterbury Regional Council, Christchurch, New Zealand.

Canterbury Regional Council, 1995b, Decisions of the Canterbury Regional Council on Submissions and Further Submissions on the Proposed Opihi River Regional Plan. Canterbury Regional Council. Christchurch.

Canterbury Regional Council, 1998, Canterbury regional policy statement, Report No. R98/4, Canterbury Regional Council, Christchurch, New Zealand. p316

Canterbury Regional Council, 1999, Water, our future: a discussion document contributing to the preparation of the Natural resources regional plan for Canterbury, Canterbury Regional Council, Christchurch, New Zealand, p219 4 folded

Clausen, B. and B. Spigel, 1999, Introductory Hydrology Course Notes, University of Canterbury, Christchurch, New Zealand.

Court of Appeal, 1991, Wellington International Airport Ltd v Air NZ, (1991) 1, NZLR 671, Court of Appeal, Wellington, New Zealand.

Darcy, H., 1856, Les fontaines publiques de la ville de Dijon, Victor Dalmont, Paris, France.

Dons, A., 1987, Hydrology and sediment regime of pasture, native forest and a pine forest catchment in the central North island, New Zealand, *in New Zealand Journal of Forestry Science,* v 17 p161-178.

Duncan, M. J., 1992, Flow Regimes of New Zealand, *in Waters of New Zealand,* M. P. Mosley. Wellington, New Zealand Hydrological Society. p 13-27.

Environment Canterbury, 2000a, Taking Surface Water and associated activities, Resource Consent Information Series - Booklet 11, Environment Canterbury, Christchurch, New Zealand. p28

Environment Canterbury, 2000b, Bores and Groundwater, Resource Consent Information Series - Booklet 10, Environment Canterbury, Christchurch, New Zealand. p25

Environment Canterbury, 2001, Discussion Draft Canterbury Natural Resources Regional Plan, Environment Canterbury, Christchurch, New Zealand. Draft Chapters 4-7 and 9

Environment Court New Zealand, 1998, Carter Holt Harvey Limited and Fletcher Challenge Forest Limited versus the Tasman District Council, Decision Number W 7/98, Environment Court, Wellington, New Zealand.

Fahey, B. D. and L. K. Rowe, 1992, Land-Use impacts, *in Waters of New Zealand,* M. P. Mosley, Wellington, New Zealand, New Zealand Hydrological Society. p 265-284.

Fahey, B. D. and A. J. Watson, 1991, Hydrological impacts of converting tussock grassland to pine plantation, Otago, New Zealand, *Journal of Hydrology New Zealand,* v 30, p98-114.

Fetter, C. W., 1994, Applied Hydrogeology Third Edition, Prentice Hall, New Jersey, USA.

Finlayson, B. and S. Brizga, 2000, Introduction, *in River Management - The Australasian Experience,* S. Brizga and B. Finlayson, International Association of Geomorphologists No. 8, Chichester, U.K.,

Finnemore, M. and J. Pettinga, in press, A Shallow Seismic Reflection Study of the Omihi Valley, North Canterbury, University of Canterbury, Christchurch, New Zealand.

Fisher, J., 2001, Evapotranspiration Methods compared on a Sierra Nevada Forest Ecosystem, Environmental Science Department, Berkeley University of California, USA. Available: http://socrates.berkeley.edu/~es196/projects/2001final/Fisher.pdf29 January 2002.

Fleming, P. H., Ed., 1996, Farm Technical Manual, Department of Farm and Horticultural Management, Lincoln University, Christchurch, New Zealand.

Fox, J. P., H. S. Gibbs and R. A. Milne, 1964, Soils and Agriculture of Kowai County, Canterbury, N.Z., N.Z. Soil Bureau Report 4/1964, New Zealand Soil Bureau, Department of Scientific and Industrial Research, Wellington, New Zealand. p53

Frieder, J., 1997, Approaching sustainability : integrated environmental management and New Zealand's Resource Management Act, Ian Axford New Zealand Fellowship in Public Policy, Wellington, New Zealand. p74

German, E. R., 2000, Regional Evaluation of Evaporation in the Everglades, South Florida Information Access SOFIA, Center for Coastal Geology, U.S. Geological Survey, U.S. Department of the Interior.
Available: http://sofia.usgs.gov/publications/papers/ET.pdf accessed 29 January 2002.

Goulter, S. W., 1982, Is December Canterbury's wettest month?, *Weather and Climate,* v 2. p25-27.

Gregg, D. R., 1964, Sheet 18 - Hurunui. Geological map of New Zealand 1:250,000, Department of Scientific Research and Development, Wellington, New Zealand.

Griffiths, E., 1980, Descriptions and analyses of soils of Waikari District, North Canterbury, New Zealand. New Zealand Soil Bureau, Department of Scientific and Industrial Research. Wellington, New Zealand. p84

Harrington, G. J., 1976, Applied use of a Mathematical Catchment Model to extend Runoff Records. *Symposium on Meteorology and Food Production,* Wellington, New Zealand, New Zealand Metrological Service.

Harris, M. G., 1983, Canterbury Gravels, Omihi Stream Section, Waipara, University of Otago, Dunedin, New Zealand,.

Hayward, S., in press, Periphyton growths in the Waipara River. MSc Thesis in Plant and Microbial Sciences, University of Canterbury, Christchurch, New Zealand.

Heiler, T., R. Plank and G. Daly 1977, Glenmark Irrigation Scheme: Final Design Report, New Zealand Agricultural Engineering Institute. Lincoln, New Zealand.

Horrell, G., 1992, Water resources of the Waipara, Kowai and Motunau catchments. Canterbury Regional Council. Christchurch. p14

Jongens, R., 2000, Maps 34 A and 34 B North Canterbury. Natural Hazards Research Centre, University of Canterbury, Christchurch, New Zealand.

Jowett, I. G., 1994, Minimum flows for native fish in the Waipara River. NIWA for Environment Canterbury. Christchurch, New Zealand.

Larking, R., in press, Establishing a relationship between Maori values for water and hydrologic monitoring of river flow: a case study of the Waipara River. Environment Canterbury. Christchurch, New Zealand.

Lockington, P. A., 1992, Data audit for the Waipara River at White Gorge: site number 65901: 1988 to 1991. Environment Canterbury. "Christchurch New Zealand,"

Loris, P., 2000, Hydrogeology of the Waipara Alluvial Basin. Christchurch, New Zealand, University of Canterbury: 2 v.

Loucks, D. P., J. S. Gladwell, Unesco/IHP-IV Project M-4.3. and International Hydrological Programme, 1999, Sustainablity criteria for water resource systems. Cambridge University Press, New York.

Martin, P. and S. Lockie, 1993, Environmental Information for Total Catchment Management: Incorporating Local Knowledge. *Australian Geographer* v24 1,

Memon, P. A., 2000, Freshwater Management Policies in New Zealand, *in Environmental Planning and Management in New Zealand,* P. A. Memon and H. Perkins. Palmerston North, New Zealand, Dunmore Press Ltd. p 234-250.

Mitchell, B., 1990, Integrated water management: international experiences and perspectives. Belhaven Press, London; New York.

Mosley, M. P., 2001a, Ashley River Flow management regime: implications of alternative minimum flows. Environment Canterbury Unpublished Report No U 01/34. Christchurch, New Zealand.

Mosley, M. P., 2001b, Ashley River: Flow management regime. Environment Canterbury Report No. U01/4, Christchurch, New Zealand. p57

New Zealand Fish and Game Council 1999, An Application for a Water Conservation Order in respect of the Rangitata River, New Zealand Fish and Game Council. Available www.mfe.govt.nz/new/rangitato_wco_2.pdf. accessed 12 February 2002.

New Zealand MfE, 2000, Making Every Drop Count Overview, Ministry for the Environment, Wellington, New Zealand.

New Zealand MfE, 1998, Flow guidelines for instream values, Ministry for the Environment, Wellington, N.Z.

New Zealand Soil Bureau, 1968, General Survey of the Soils of the South Island, New Zealand, N.Z. Soil Bureau Bulletin No 27. New Zealand Soil Bureau, Department of Scientific and Industrial Research, Wellington, New Zealand. p404

New Zealand Soil Bureau, 1968, Soils of New Zealand, Government Printer, Wellington, New Zealand.

New Zealand Standard, 1973, Code of Practice for the Design, Installation and Operation of Sprinkler Irrigation Systems NZS5103, Standards Association of New Zealand, Wellington, New Zealand.

Nicol, A., 1991, Structural styles and kinematics of deformation on the edge of the New Zealand plate boundary zone, mid-Waipara region, North Canterbury. University of Canterbury, Christchurch, New Zealand. p 171.

Nicol, A., B. Alloway and P. Tonkin, 1994, Rates of deformation, uplift, and landscape development associated with active folding in the Waipara area of north Canterbury, New Zealand. *in Tectonics* v 13. p 1327-1344.

Nicol, A. and J. K. Campbell, 2001, The Impact of Episodic fault-related folding on late Holocene degradation terraces along the Waipara River, New Zealand. *New Zealand Journal of Geology and Geophysics,* v44, p145-156.

NIWA, 1996, Stream Gauging, unpublished course notes for Canterbury Regional Council. National Institute of Water and Atmospheric Research Ltd., Christchurch, New Zealand.

NIWA, 1998, NIWA Climatic Database, National Institute of Water and Atmospheric Research Ltd. accessed 2001.

NIWA, 1999, El Niño and Forecasting Seasonal Climate, National Institute of Water and Atmospheric Research Ltd. Available:http://katipo.niwa.cri.nz/ClimateFuture/El_Nino.htm. accessed 13 February 2001.

NOAA National Climatic Data Centre, 1998, The Top 10 El Niño Events of the 20th Century, National Oceanic and Atmospheric Administration Available:http://lwf.ncdc.noaa.gov/oa/climate/research/1998/enso/10elnino.html. Accessed 25 September 2001.

O'Donnell, C. F. J. and S. G. M. Moore, 1983, The Wildlife and Conservation of Braded River Systems in Canterbury. Faunal Survey Report No 33, New Zealand Wildlife Service. Christchurch, New Zealand.

Pattle Delamore Partners and Canterbury Regional Council, 1996, Preliminary assessment of stream depletion effects from groundwater abstractions in the Waipara River catchment. Canterbury Regional Council, Christchurch, New Zealand.

Penman, H. L., 1948, Natural evaportranspiration from open water, bare soil and grass. Royal Society London Series A.

Pettinga, J., 2001, Presentation at a Field Day for the Omihi Irrigation Society.

Priestley, C. H. B. and R. J. Taylor, 1972, On the Assessment of surface heat flux and evaporation using large scale parameters. *Monthly Weather Review* v100 p81-92.

Richardson, J., 1994, Fisheries values of the Waipara River Catchment. Environment Canterbury, Christchurch, New Zealand.

RMA W100/95, 1995, Decision No. W100/95 in the Matter of the Resource Management Act 1991, over appeals against the Canterbury Regional Council's decision to grant a consent to Maungatahi Farm Ltd. to abstract water from the Waipara River, Judge Kenderdine presiding. The Planning Tribunal, Wellington,.

Rodda, J. C., 1976, Basin Studies. *in Systematic hydrology.* J. C. Rodda, R. A. Downing and F. M. Law, Newnes-Butterworth, London, U.K..

Rosenberg, N. J., B. L. Blad and S. B. Verma, 1983, Microclimate the Biological Environment. J Wiley and Sons Inc, USA.

Rosenberg, N. J., H. E. Hart and K. W. Brown, 1968, Evapotranspiration - Review of Research. Agr. Exp. Station Misc. Bull. No. 20, Nebraska, USA. p80

Rowe, L. K. and B. D. Fahey 1991, Hydrology and water chemistry changes after harvesting small indigenous forest catchments, Westland, New Zealand. International Association of Hydrological Sciences, Publication No. 20, p259-266.

Ryan, A. P. 1987, The climate and weather of Canterbury, including Aorangi. New Zealand Miscellaneous Publication 115 17, Meteorological Service, Wellington, New Zealand.

Smith, P. J. T., 1987, Variation of water yield from catchments under introduced pasture grass and exotic forest, east Otago. *Journal of Hydrology New Zealand,* v 26: p175-184.

Sturman, A. P., 1986, Atmospheric Circulation and Monthly Precipitation in Canterbury, New Zealand. *Weather and Climate,* v 6: p7-14.

Syme, G. J., J. E. Butterworth and B. E. Nancarrow, 1994, National Whole Catchment Management - A Review and Analysis of Processes. The Land and Water Resources Research and Development Corporation, Canberra, Australia.

Tasman District Council, Cawthron Institute and Landcare Research, 2002, Integrated Catchment Management for the Motueka River, Landcare Research Available http://icm.landcare.cri.nz/index.htm. accessed 14 February 2002.

Taylor, M. A. W., 1971, Assessment of a mathematical model for runoff prediction in New Zealand : a thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering in Agricultural Engineering in the University of Canterbury Lincoln College, Christchurch, New Zealand

Te Runanga o Ngai Tahu, 1999, Te Runanga o Ngai Tahu Freshwater Policy. Christchurch, New Zealand.

Thompson, S. A., 1999, Hydrology for water management. A.A. Balkema, Rotterdam.

Thornthwaite, C. W., 1948, An approach towards a rational classification of climate. *Geographical review* v38: p55-94.

Thornthwaite, C. W. and J. R. Mather, 1955, The Water Balance. Drexel Institute of Technology, Philadelphia, USA.

Tipa, G. and New Zealand MfE, 1999, Environmental performance indicators : Taieri River case study. Ministry for the Environment, Wellington, N.Z.

Todd, C., 2000, Statement of C. J. Todd for the Director General of Conservation in the matter of the Proposed Hurunui District Plan: Proposed Variations 19 Significant Landscapes and 38 Forestry. Canterbury Conservancy Office of the Department of Conservation, Christchurch, New Zealand.

Toebes, C. and W. B. Morrissey, 1970, Representative basins of New Zealand, 1970. New Zealand Ministry of Works - Water and Soil Division, Miscellaneous Publication No. 7. Wellington, New Zealand.

Toebes, C. and B. R. Palmer, 1969, Hydrological Regions of New Zealand Miscellaneous Hydrological Publication No 4. Water and Soil Division, New Zealand Ministry of Works,. p45p

UNESCO - United Nations Educational Scientific and Cultural Organisation, 2002, HELP Hydrology for the Environment, Life and Policy, UNESCO Natural Sciences Available http://www.nwl.ac.uk/ih/help/. Accessed 12 February 2002.

Wilson, D. D., 1963, Geology of Waipara Subdivision Amberley and Motunau Sheets S68 and S69, Government Printer, Wellington, New Zealand.

Wilson, D. D., 1983, Glenmark Irrigation Scheme Hydrological Study. Christchurch, New Zealand. p25

World Meteorological Organisation, 1962, Guide to Climatological Practices. World Meteorological Organisation.

Young, G. J., J. C. I. Dooge and J. C. Rodda, 1994, Global Water Resource Issues. Cambridge University Press, Cambridge, Great Britain.

Yousif, H. M. S., 1987, The Application of remote sensing to geomorpological neotectonic mapping in North Canterbury. University of Canterbury, Christchurch, New Zealand,.

APPENDICES

The Appendices for this document are included on the attached CD, and are arranged according to chapters. The Appendices include:

CHAPTER 3 CLIMATE

Appendix 3.1 Description of the rain-gauges of the Waipara area and inclusion of the monthly precipitation data.

Appendix 3.2 Calculation of 1951-2000 precipitation normals for the rain-gauges of the Waipara area.

Appendix 3.3 Evapo-transpiration data from the Waipara area and the calculation of 1951-2000 Priestly Taylor evapo-transpiration normals for the climate stations in the Waipara Area.

Appendix 3.4 Thornwaite soil water balance undertaken at 14sites in the Waipara Area.

CHAPTER 4 SURFACE WATER RESOURCES AND USE

Appendix 4.1 Regression Relationship between flow in the Waipara River at White Gorge and flow at the Teviotdale Recorder Site.

Appendix 4.2 Description of Gauging sites and inclusion of gauging data.

Appendix 4.3 Regression Relationship between flow in the Waipara River at White Gorge and flow at other sites along the river.

Appendix 4.4 Description of the two flow models used to extend the flow record for the Waipara River at White Gorge.

Appendix 4.5 Description of springs located in the Waipara Catchment.

CHAPTER 5 GROUNDWATER RESOURCES AND USE

Appendix 5.1 Borehole details from boreholes recently drilled in the Waipara Area.

Appendix 5.2 Calculation of groundwater fluctuations in the Waipara area over the 2000-2001 Summer.

Appendix 5.3 Borehole details from the boreholes within which continuous water level monitoring was undertaken.

CHAPTER 6 WATER BALANCE AND RESOURCE SUMMARY

Appendix 6.1 Groundwater outflow calculations for flow through the gravels which underlie the Glasnevin Flats

CHAPTER 7 WATER RESOURCE MANAGEMENT

Appendix 7.1 Interview Questionnaire and format which was used during stakeholder interviews.